Fuel Cell Power Plant Initiative

Final Report - Volume I
Solid Oxide Fuel Cell/Logistics Fuel Processor 27 kWe Power System Demonstration for ARPA

Prepared by:
S. E. Veyo, Manager, SOFC Projects
Westinghouse Science & Technology Center
1310 Beulah Road
Pittsburgh, PA 15235-5098

T. E. Dowdy, Project Manager
Westinghouse Electric Corporation
4400 Alafaya Trail
Orlando, FL 32826-2399

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SUMMARY

This report describes the successful testing of a 27 kWe Solid Oxide Fuel Cell (SOFC) generator fueled by natural gas and/or a fuel gas produced by a brassboard logistics fuel preprocessor (LFP). The test period began on May 24, 1995 and ended on February 26, 1996 with the successful completion of all program requirements and objectives. During this time period, this power system produced 118.2 MWh of electric power. No degradation of the generator's performance was measured after 5,582 accumulated hours of operation on these fuels:

Local natural gas	3,261 hours
Jet fuel reformate gas	766 hours
Diesel fuel reformate gas	1,555 hours

This SOFC generator was thermally cycled from full operating temperature to room temperature and back to operating temperature six times, because of failures of support system components and the occasional loss of test site power, without measurable cell degradation. Numerous outages of the LFP did not interrupt the generator's operation because the fuel control system quickly switched to local natural gas when an alarm indicated that the LFP reformate fuel supply had been interrupted.

The report presents the measured electrical performance of the generator on all three fuel types and notes the small differences due to fuel type. Operational difficulties due to component failures are well documented even though they did not affect the overall excellent performance of this SOFC power generator.

The final two appendices describe in detail the LFP design and the operating history of the tested brassboard LFP.

1. INTRODUCTION

This Advanced Research Projects Administration (ARPA) Logistics Fuels Program, administered under NASA Lewis Contract NAS3-27022, consisted of a multi-year program to develop and demonstrate the technology required for the use of logistic fuels in Solid Oxide Fuel Cell (SOFC) Power Systems for fixed-base applications. The three primary objectives of the program were:

1. To develop a logistics fuel pre-processor (LFP) for operation of an SOFC Demonstration Module on DF-2 and JP-8.
2. To prepare an SOFC module design that satisfies DOD generator set requirements for fixed-base deployment and to demonstrate salient features of the design in an SOFC Demonstration Module having a stack peak power of 27 kWe dc.
3. To design and build a brassboard LFP and to test it with the SOFC Demonstration Module.

The SOFC module and its associated subsystems was supplied by the Westinghouse Electric Corporation (WEC). Haldor Topsoe Inc. (HTI), a subcontractor to WEC, designed the LFP to remove the sulfur content and to prepare a methane richreformate gas from two logistics fuels for use in the SOFC Demonstration Module. Haldor Topsoe A/S (HTAS), under subcontract to HTI, conducted bench scale reformation tests in Copenhagen, Denmark. Southern California Edison (SCE), under a SCE subcontract, provided a test site at its Highgrove Generating Station located at Grand Terrace, California for the testing program.

A detailed description of the LFP written by HTI is included in Appendix E.

Also, a detailed operating history of the LFP, written by the operator of the brassboard LFP, is presented in Appendix F.

2. SOFC GENERATOR DESCRIPTION

The SOFC and SOFC generator are described in a companion report titled "Final Report - Volume II - Preliminary Design of a Fixed-Base LFP/SOFC Power System".

Figure 2.1 is an isometric front view of the SOFC generator unit which was installed at the Highgrove test site in Grand Terrace, California and tested from June 7, 1994 until May 2, 1995. This unit test was funded by SCE, EPRI, DOE/FETC, and Westinghouse. The SOFC generator contained 576 porous support tube (PST) fuel cells.

For this Advanced Research Projects Agency (ARPA) test program, some changes were made to the above SOFC power generating unit. The 576 fuel cell generator module was removed and replaced with a virtually identical one which contained 576 air electrode supported (AES) fuel cells. Also, the following modifications were made to the unit's fuel supply system:

a) The natural gas (NG) compressor, accumulator, and NG flow meter were removed.

b) A NG mass flow controller was installed to both meter and control the natural gas feed to the generator.

c) A logistics fuel reformate gas mass flow controller was installed to both meter and control the reformate gas feed to the generator.

d) One bellows meter (100 psig) with temperature compensation for absolute NG flow measurement was installed in the natural gas supply line.

e) One bellows meter (100 psig) with temperature compensation for absolute LF flow measurement was installed in the reformate gas supply line.

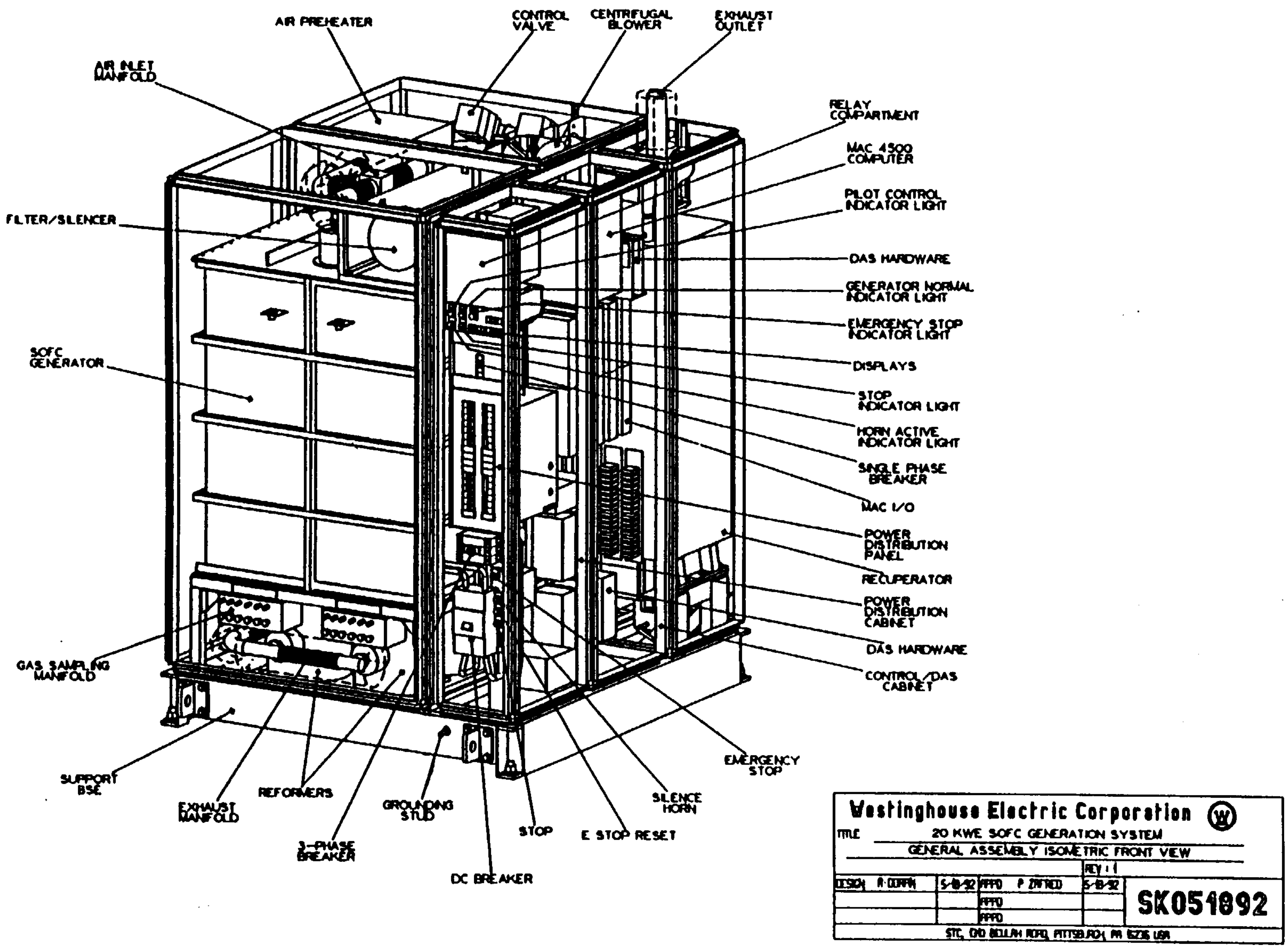

Figure 2.1 — Isometric front view of the SOFC generator unit.

f) Two NG desulfurizer tanks with catalyst beds were installed in the natural gas supply line.

g) Two outdoor redundant AC shutoff solenoid valves were installed for safety reasons.

h) All fuel system DC solenoid valves were replaced with AC powered solenoid valves.

The control system was reprogrammed in the RUN state to permit operation on either NG or LFP fuel. Should the LFP fuel supply fail, the system would automatically substitute NG in its place. The unit also could operate on a combination of these two fuels if necessary. This latter situation occurred during:

1. Switchover from NG to LF operation.
2. Periods where the supply pressure from the LF system drops due to sudden high demand or component malfunctioning.

Figure 2.2 shows an example of this control system capability during the operation of the unit on January 23, 1996. The unit was operating steadily on LFP fuel and suddenly at around 04:53, the LFP fuel supply dipped and became erratic for over 40 minutes. (Notice in Figure 2.2 how the controller was able to add local NG to keep the unit running until the LFP fuel supply once more steadied itself after 05:40.) On several occasions, the LFP fuel supply was reduced to zero, but the control system was still able to add NG fast enough to prevent an automatic system shutdown from occurring.

2.1 NATURAL GAS DESULFURIZATION AND METERING EQUIPMENT

For this project, a special NG desulfurization and flow measuring subsystem was designed, built, and installed outside and adjacent to the building which housed the SOFC generator unit. The desulfurization was accomplished by passing the 40.5 psig NG through two series connected tanks each filled with 2 ft^3 of activated charcoal catalyst (C8-7-01 from United Catalyst, Inc.). Then,

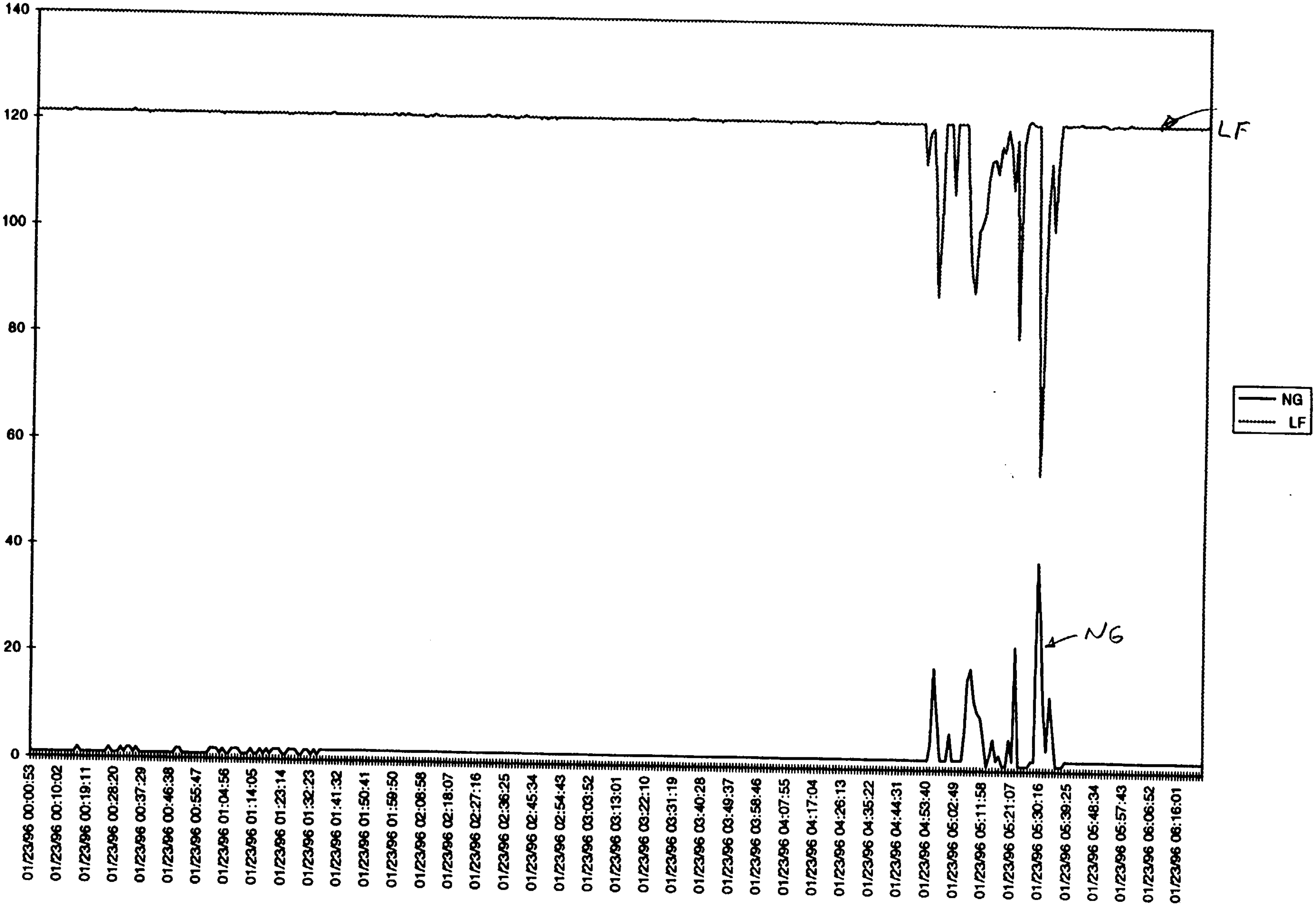

Figure 2.2 — Example of control system capability during operation.

the gas was filtered once again and directed to a 100 psig American Meter Co. bellows meter for flow measurement. The flow lines were valved and instrumented to permit catalyst bed change out without interruption of generator operation and for correction of the metered gas flow to standard conditions (0°C, 14.7 psia).

For the logistics reformate fuel, no desulfurization was required. Only the gas metering was accomplished in the cabinet at a supply pressure of around 75 psig. with a second bellows type gas meter.

The bellows type gas meters used were automatically temperature compensated to 60°F and had an accuracy of ±1.0% of reading over a 100 to 1 flow range. In general, these meters were only checked during V-I tests, as well as for the initial calibration check outs of the fuel supply system electronic gas mass flow controllers.

2.2 TEST HISTORY

Table 2.1 presents an events chronology for the test period beginning on March 24, 1995 and ending on February 26, 1996. This table records the major events from the perspective of the SOFC generator's operator. (Appendix E contains a report written by the LFP operator which concentrates on the performance of the LFP within this test period.)

Figure 2.3 is a plot of the generator's terminal voltage and current versus time for the entire test period. Figure 2.4 identifies the fuel type supplying the SOFC generator for the entire test period.

Of the 6 unit shutdowns which occurred during this testing, three were caused by a problem with the belt-driven blower air supply system, and one each resulted from the following causes:

1. Large leak in the air supply plumbing caused by the failure of a hose clamp joint.
2. A trip out of the LFP which caused the generator to trip also.
3. Loss of site power.

Table 2.1 — ARPA Test (May 24, 1995 to February 26, 1996) Chronology of Events

Date	Event	Comments
5/24/95	Initial startup.	
6/12-25/95	V-I tests on local PNG.	
6/16/95	Unit is shut down by operator.	Air leakage at blower exit pipe is discovered and repaired.
6/20/95	Second startup.	
6/21-29/95	V-I tests on local PNG.	
7/20/95	Unit is shut down.	Blower/motor fails and new unit is installed.
7/25/95	Third startup.	
8/24/95	First switch over from natural gas to LFR gas from jet fuel	
9/19/95	Unit is shut down.	Blower noise is cause of STOP. Blower and motor replaced.
9/29/95	Fourth startup is aborted.	Air heater fails and must be replaced.
9/30/95	Fourth startup.	
10/3-4/95	V-I testing on jet fuel LFR.	
10/11/95	Begin running on reformed diesel fuel.	
10/25/95	Unit is shutdown.	Blower and motor replaced. NG desulfurizer beds changed out.
11/14/95	Fifth startup.	
2/2/96	Unit is shutdown.	LFP trip causes SOFC system to go to STOP.
2/6/96	Sixth startup.	
2/15-16/96	V-I testing on diesel LFR.	
2/19/96	Unit is shut down.	Loss of site power causes SOFC to go to STOP
2/21/96	Seventh startup.	
2/22-23/96	V-I tests on local PNG.	
2/26/96	Final unit shutdown.	End of project.

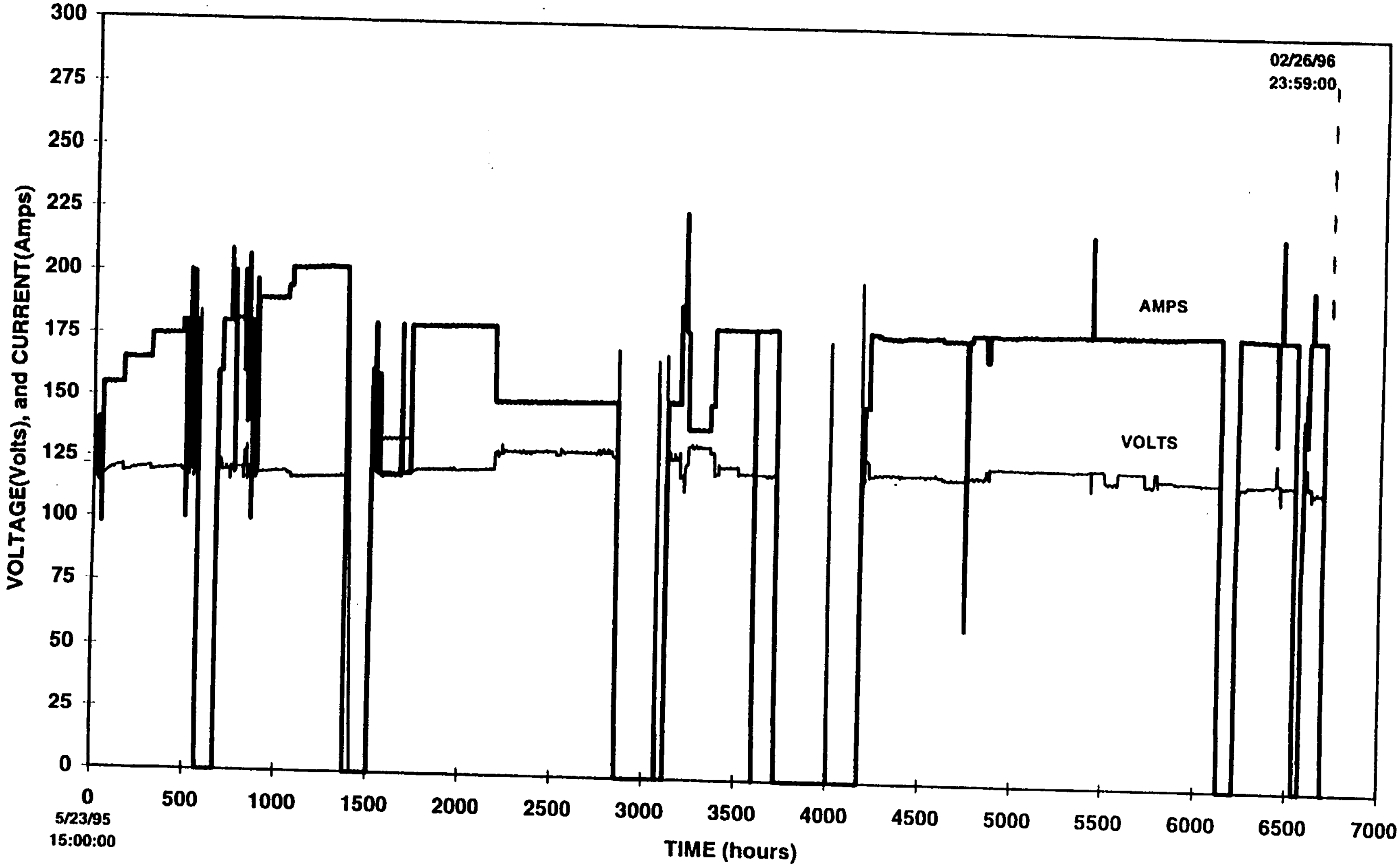

Figure 2.3 — ARPA/SCE SOFC generator terminal voltage and current.

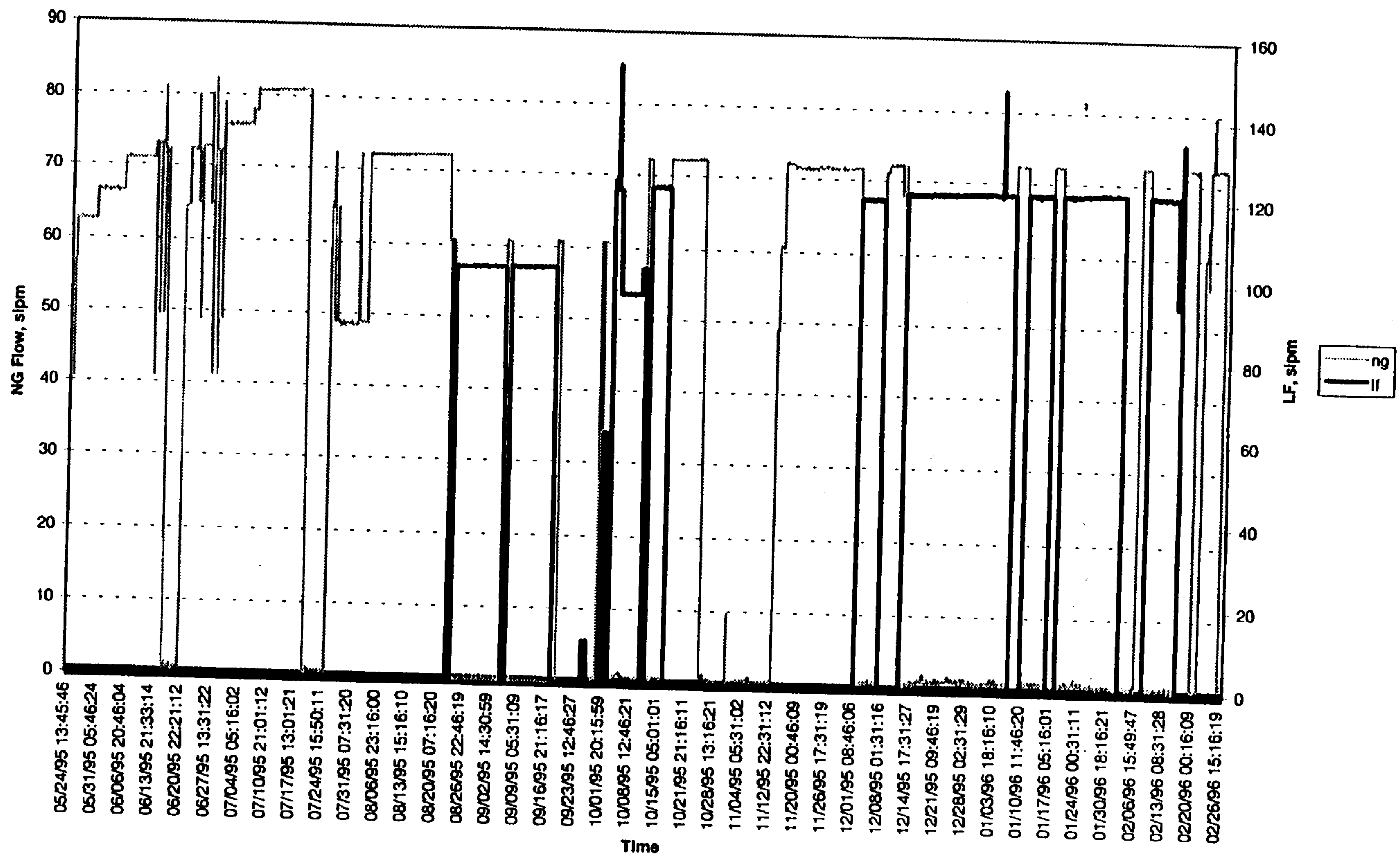

Figure 2.4 — ARPA/"SCE fuel flows.

The air electric heater failed during a restart attempt on September 29, 1995. The natural gas desulfurizer catalyst beds were replaced only once.

In general, aside from the air blower, most of the generator's electrical and mechanical subsystems performed very well throughout the program. The unit logged thousands of unattended operating hours and protected itself very adequately during the six periods when cell damage could have occurred.

2.3 GENERATOR V-I TESTING RESULTS

During the testing period from May 24, 1995 to February 26, 1996, four major V-I test series were run:

1. Early in the test period June 13-29, 1995 on local NG fuel. See data in Appendix A.
2. End of run on logistics reformate from jet fuel on October 4, 1995. See data in Appendix B.
3. End of run on logistics reformate from diesel fuel on February 15-16, 1996. See data in Appendix C.
4. End of the test period February 22-26, 1996 on local natural gas fuel. See data in Appendix D.

In general, these tests served as a base line against which future tests could be compared, to determine the health and well being of the generator cells, or to record the performance of the SOFC generator on a particular fuel species.

Each individual V-I test was a steady state test — the data were not recorded until all the measured parameters had stopped changing. Also, for all tests, the fuel flow was measured using the outdoor bellows gas meter corrected to standard conditions (i.e., 0°C, 14.7 psia).

2.4 COMPARISON OF GENERATOR PERFORMANCE WITH AND WITHOUT BY-PASS VALVE OPERATION.

During the V-I tests in test Series 1, the unit was run at generator currents from 100 to 200 amperes at generator set point temperature of 1020, 1035, and 1050°C. Finally, the generator was tested both with the ejector by-pass valve open and closed. Table 2.2 summarizes the performance of this unit during this testing and shows the influence of the fuel bypass system with this local natural gas. As the table points out, the most benefit from the bypass system occurs at the lowest generator operating temperature.

Table 2.2 — ARPA Generator Performance on Natural Gas (with ejector by-pass closed and with by-pass operating).

Generator Current (amps)	Tgen (max.) °C	Terminal Voltage (By-Pass Valve Open)*	Terminal Voltage (By-Pass Valve Closed)**	ΔV_T (Open-Closed By-Pass Valve)
100	1050	138.7	138.5	0.2
120	1050	135.6	135.0	0.6
140	1050	132.0	131.3	0.7
160	1050	128.2	127.4	0.8
180	1050	124.0	123.2	0.8
200	1050	119.4	118.7	0.7
100	1035	138.6	138.5	0.1
120	1035	135.6	134.6	1.0
140	1035	131.8	130.8	1.0
160	1035	127.6	127.0	0.6
180	1035	122.8	122.6	0.2
200	1035	117.8	118.0	-0.2
100	1020	141.7	138.5	3.2
120	1020	136.9	134.2	2.7
140	1020	131.9	130.0	1.9
160	1020	126.9	125.4	1.5
180	1020	121.9	120.6	1.3
200	1020	117.0	115.7	1.3
*O:C ≈ 2.1 on average per quad. Test dates 6/26-29/95.				
**Test dates 6/13-15/95. O:C at maximum				

2.5 COMPARISON OF GENERATOR PERFORMANCE ON LOCAL NATURAL GAS AT START AND END OF THIS PROGRAM

Table 2.3 contains steady state test data extracted from Appendix A and D which compares the unit's performance on local natural gas at the start and end of this program. From June 15, 1995 to February 22, 1996, this unit operated for over 5,000 hours on three fuels (NG, jet fuel reformate, and diesel fuel reformate). Also, for various reasons, this unit experienced 5 complete thermal cycles from operating temperature to room temperature in this time period. Nevertheless, the data in Table 2.3 shows no measurable difference in performance in this unit over this time period when operating on local natural gas.

Table 2.3 — ARPA Generator (on local natural gas).

Test Date	Generator Current (amps)	Generator Voltage (volts)	Power (kW)	N.G. flow (bellows)	Tgen (°C)
2/23/96	180.0	122.2	22.0	71.5	1035
6/15/95	180.6	120.7	21.8	71.2	1035
2/23/96	200.0	117.7	23.5	79.6	1035
6/15/95	199.1	118.0	23.5	79.8	1035
2/22/96	138.1	130.6	18.1	55.3	1035
6/15/95	140.2	130.1	18.3	56.0	1035
2/22/96	158.9	124.7	19.8	62.9	1035
6/15/95	160.0	126.6	20.4	65.7	1035
2/23/96	200.0	116.6	23.3	79.3	1050
6/14/95	200.6	118.5	23.8	80.4	1050
2/23/96	180.4	121.8	22.0	71.7	1050
6/14/95	180.6	122.9	22.2	72.4	1050
2/26/96	180.4	119.0	21.4	71.4	1020
6/12/95	179.0	120.3	21.5	72.4	1020
2/22/96	158.9	123.4	19.6	63.1	1020
6/13/95	159.0	125.4	19.9	64.4	1020

Note: The generator operated for over 5,000 hours from 6/15/95 to 2/22/96 and was subjected to 5 complete thermal cycles.

2.6 COMPARISON OF GENERATOR PERFORMANCE ON THREE FUEL TYPES

In order to compare the performance of this generator on the three fuel types run during this program, 180 generator ampere test data have been extracted from the V-I test data from Appendix B, C, and D and are shown in Table 2.4. The comparison of performance is confounded only in that not all three tests were run at identical cell average temperatures. However, from past testing, it is known that the sensitivity of these cells, at currents of 60 amps/cell is approximately 0.75 mV/cell°C.

Thus, normalizing all three tests to an average cell temperature of 945°C results in the power outputs shown in the last column in this table. Obviously, accounting for the temperature variations, these data show that the generator performance at 180 amperes was identical for all three fuels within the accuracy of the control instrumentation.

2.7 GAS CHROMATOGRAPHY

For this program, an on-line high-tech gas chromatograph (model P200 Gas Analyzer from MTI Analytical Inst.) was leased in order to analyze the following gas mixtures:

1. Local California NG.
2. Logistics pre-processor reformate gas.
3. Generator reformer exit gas (analysis of this gas composition provides a measurement of the oxygen to carbon ratio in the gas stream entering this reformer).

A separate chromatograph calibration subroutine was determined for each of these three gas mixtures by first blending a known similar mixture which contained the various gas species in each one.

Table 2.4 — Comparison of Generator Performance on Three Fuels at Generator Current = 180 amps.

Fuel	Test Date	Test Time	Run No.	Tgen (°C)	Fuel Flow (SLPM)	Generator Current (amps)	Terminal Voltage (volts)	Power (kW)	Avg. Cell Temp. (°C)	kW_n*
Local NG	2/23/96	7:50	6	1035	71.5	180	122.2	22.0	945	22.0
Jet Fuel Reformate	10/4/95	16:20	7	1045	121.7	180	126.3	22.7	977	21.90
Diesel Fuel Reformate	2/15/96	9:57	4	1035	120.4	180	123.2	22.2	953	22.0

*Normalized to an average cell temperature of 945°C assuming a cell temperature sensitivity of 0.75 mV/cell°C.

Table 2.5 shows a typical analysis of the local California NG.

Table 2.6, Table 2.7, and Table 2.8 show GCA analyses of generator reformer exit gas along with the calculated O:C ratios for all four generator quadrants for three tests performed in June 1995.

Appendix F presents GCA analysis of LFP reformate gas.

Table 2.5 — GCA Analysis of Local California Natural Gas

Normalization Report

Name	Amount	Units	RT	Min	Max	Mean	%SD
METHANE (C1)	96.608	%	19.570	87.990	97.214	90.643	4.701
ETHANE (C2)	2.428	%	22.450	2.007	6.004	4.885	36.789
PROPANE (C3)	0.934	%	29.810	0.757	4.003	3.061	49.355
N-BUTANE (C4)	0.031	%	53.170	0.022	2.004	1.411	67.657

Channel: A
Current Time: Aug 22, 1995 08:50:49
Method: c:\ezchrom\methods\scepng.
File : C:\EZCHROM\chrom\SCEPNG$.1
Data file creation time: Aug 22, 1995 08:49:18
Instrument ID:
Column Type:
Carrier Gas:
Column Head Pressure: 27.1 psi
Column Temperature: 124 C
Instrument Gain: LOW
Sample Time: 10 seconds
Inject Time: 50 milliseconds
Run Time: 60 seconds

Table 2.6 — GCA Analysis of Generator Reformed Exit Gas for all Four Quadrants
(June 27, 1995)

SCE Gas Chromatograph Analysis

JUNE 27 1995
BYPASS VALVE ACTIVE
215 AMPS 1050 C 82.7% F.U.

GC Results	P2103	P2203	P2303	P2403
H2	58.79	58.05	56.83	56.05
O2	0.18	0.18	0.18	0.19
N2	3.22	3.42	3.36	3.63
CO	21.85	21.73	21.81	20.42
CO2	22.32	22.21	23.71	24.62
CH4	1.36	1.47	0.60	0.97
Total	107.72	107.06	106.48	105.88
H2 %	54.57	54.22	53.37	52.94
O2 %	0.17	0.17	0.16	0.18
N2 %	2.99	3.19	3.15	3.42
CO %	20.29	20.30	20.48	19.29
CO2 %	20.72	20.74	22.26	23.25
CH4 %	1.26	1.38	0.56	0.92
Total	100.00	100.00	100.00	100.00
Dry Products of Reformation, only:				
H2 %	56.35	56.11	55.20	54.92
CO %	20.95	21.00	21.19	20.01
CO2 %	21.39	21.47	23.03	24.12
CH4 %	1.30	1.42	0.58	0.95
TOTAL	100.00	100.00	100.00	100.00
Performance:				
X, from CxHy	1.027	1.027	1.027	1.027
y, from CxHy	4.009	4.009	4.009	4.009
H2O	26.208	26.692	31.044	31.138
O:C	2.061	2.065	2.194	2.205
FU (P1 only)	0.522	0.523	0.555	0.558
Fuel analysis				
CH4	0.9403	0.9403	0.9403	0.9403
C2H6	0.0276	0.0276	0.0276	0.0276
C3H8	0.0055	0.0055	0.0055	0.0055
C4H10	0.0038	0.0038	0.0038	0.0038
CxHy:				
x	1.0272	1.0272	1.0272	1.0272
y	4.0088	4.0088	4.0088	4.0088

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Table 2.7 — CGA Analysis of Generator Reformed Exit Gas for all Four Quadrants (June 28, 1995).

SCE Gas Chromatograph Analysis

JUNE 28 1995
BYPASS VALVE ACTIVE

160 AMPS 1020 C	82.0% F.U.	
GC Results	P2103	P2403
H2	61.94	59.91
O2	0.18	0.24
N2	4.73	5.13
CO	23.95	22.44
CO2	23.23	24.94
CH4	0.91	0.66
Total	114.94	113.32
H2 %	53.89	52.87
O2 %	0.16	0.21
N2 %	4.12	4.52
CO %	20.84	19.80
CO2 %	20.21	22.01
CH4 %	0.79	0.58
Total	100.00	100.00
Dry Products of Reformation, only:		
H2 %	56.29	55.50
CO %	21.77	20.79
CO2 %	21.11	23.10
CH4 %	0.83	0.61
TOTAL	100.00	100.00
Performance:		
X, from CxHy	1.027	1.027
y, from CxHy	4.009	4.009
H2O	27.333	30.114
O:C	2.089	2.182
FU (P1 only)	0.529	0.552
Fuel analysis		
CH4	0.9403	0.9403
C2H6	0.0276	0.0276
C3H8	0.0055	0.0055
C4H10	0.0038	0.0038
CxHy:		
x	1.0272	1.0272
y	4.0088	4.0088

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Table 2.8 — CGA Analysis of Generator Reformed Exit Gas for all Four Quadrants (June 29, 1995)

SCE Gas Chromatograph Analysis

JUNE 29 1995
BYPASS VALVE ACTIVE
195 AMPS 1020 C 52.5% F.U.

GC Results	P2103	P2203	P2303	P2403
H2	61.66	60.70	59.24	58.93
O2	0.17	0.22	0.21	0.22
N2	3.78	4.08	4.01	4.22
CO	22.34	22.11	21.96	20.97
CO2	23.82	23.60	25.39	25.76
CH4	1.65	1.79	0.87	1.23
Total	113.42	112.47	111.69	111.31
H2 %	54.36	53.97	53.04	52.94
O2 %	0.15	0.19	0.19	0.19
N2 %	3.33	3.61	3.59	3.79
CO %	19.70	19.65	19.68	18.83
CO2 %	21.00	20.98	22.73	23.14
CH4 %	1.46	1.59	0.78	1.10
Total	100.00	100.00	100.00	100.00
Dry Products of Reformation, only:				
H2 %	56.32	56.10	55.12	55.14
CO %	20.40	20.43	20.45	19.62
CO2 %	21.76	21.81	23.62	24.10
CH4 %	1.51	1.65	0.81	1.15
TOTAL	100.00	100.00	100.00	100.00
Performance:				
X, from CxHy	1.027	1.027	1.027	1.027
y, from CxHy	4.009	4.009	4.009	4.009
H2O	25.883	26.250	30.831	30.105
O:C	2.056	2.057	2.195	2.183
FU (P1 only)	0.520	0.521	0.556	0.552
Fuel analysis				
CH4	0.9403	0.9403	0.9403	0.9403
C2H6	0.0276	0.0276	0.0276	0.0276
C3H8	0.0055	0.0055	0.0055	0.0055
C4H10	0.0038	0.0038	0.0038	0.0038
CxHy:				
x	1.0272	1.0272	1.0272	1.0272
y	4.0088	4.0088	4.0088	4.0088

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3. CONCLUSIONS

This very successful project demonstrated the operation of an SOFC generator on the reformate of a LFP. The generator's control system permitted smooth transitions between local natural gas and logistics fuel reformate gas. This permitted continuous operation despite periodic shut downs of the LFP due to equipment problems and/or malfunctions.

Based on the results of this program, the following conclusions can be made:

1. An SOFC generator designed for NG fuel can be operated with no performance degradation on the reformate gas from an LFP processing either JP-8 or DF-2.
2. The primary limitations of this power system were related to the failures of blowers, pumps, heaters, and instrumentation sensors.
3. This tested LFP/SOFC Power System performed up to all expectations and satisfied all of the contractual objectives set for it.

APPENDIX A — V-I TEST RECORDED DATA

TEST DATES: June 12-15, 1995; June 21-29, 1995

FUEL: Local Natural Gas

ARPA / SCE AES Generator																
V-I Curve Data @ Tgen SP = 1020 nominal																
Run#	1.0	2.0	2.1	3.0	4.0	4.1	4.2	4.3	5.0	5.1	6.0	6.1	7.0	7.1	8.0	8.1
Date	6/12/95	6/12/95	6/12/95	6/13/95	6/13/95	6/13/95	6/13/95	6/13/95	6/13/95	6/13/95	6/13/95	6/13/95	6/13/95	6/13/95	6/13/95	6/13/95
Time	15:32	17:54	18:09	07:15	11:23	11:43	13:02	13:19	15:37	16:00	16:46	17:06	18:12	18:30	19:15	19:26
PNG (psig)	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4
Patm (inch Hg)	29.09	29.08	29.08	29.06	29.08	29.08	29.08	29.08	29.08	29.08	29.08	29.08	29.08	29.08	29.08	29.08
Tamb (deg C)	40.7	36.6	36.4	24.0	37.9	38.1	40.2	40.4	37.2	36.5	34.6	34.4	32.6	32.1	31.6	31.2
Time (.01 MCF) (sec)	828.92	***	807.37	809.87	***	1015.95	***	1025.75	***	1422.95	***	1187.15	***	908.22	***	813.46
	72.4		72.8			57.7				41		48.6		64.3		
NGSLPM (Bellows Meter)	70.5	***	72.4	72.2	***	57.5	***	57.0	***	41.1	***	49.3	***	64.4	***	71.9
NGSLPM (MFC measured)	71.1	73.2	73.2	73.1	57.5	57.5	57.5	57.7	41.8	41.7	49.5	49.8	65.3	65.2	73.1	73.1
NGSLPM (MFC set point)	71.6	73.5	73.6	73.5	57.9	57.9	57.9	57.9	42.0	41.8	49.8	49.9	65.5	65.5	73.5	73.4
Pnoz (measured) (kg/cm^2)	2.03	2.06	2.04	2.01	1.44	1.47	1.45	1.46	0.85	0.83	1.12	1.12	1.71	1.72	2.02	2.01
Pnoz (set point) (kg/cm^2)	1.40	1.48	1.46	1.45	1.02	1.03	1.03	1.03	0.67	0.66	0.83	0.83	1.24	1.24	1.45	1.46
Tnoz (deg C)	30.6	30.5	30.1	27.4	29.8	28.7	28.0	28.1	28.8	28.9	29.1	29.0	29.0	28.9	28.8	28.6
Fuel Util (%)	82.2	82.4	82.4	82.3	81.5	81.4	81.7	81.5	80.6	80.3	80.9	80.9	81.7	82.2	82.3	82.6
Air SLPM	3567	3581	3553	3581	3098	3072	3072	3085	2501	2523	2806	2806	3272	3272	3581	3561
Stoichs	6.3	6.2	6.2	6.2	6.8	6.8	6.8	6.8	7.9	7.9	7.3	7.3	6.4	6.4	6.2	6.2
Amps (setpoint)	174.0	179.0	179.0	179.0	140.0	140.0	140.0	140.0	102.0	102.0	121.0	121.0	159.0	159.0	179.0	179.0
Amps (measured)	175.7	180.9	180.6	180.6	141.1	140.0	140.8	140.8	100.3	100.3	120.2	120.5	160.4	160.1	180.6	180.6
Vt (Quad Sum)	121.9	120.7	120.3	120.7	131.1	130.2	130.1	130.1	138.8	138.9	134.6	134.5	125.4	125.4	120.5	120.7
Tgen1	1019	1019	1021	1019	1021	1021	1021	1019	1019	1019	1019	1018	1021	1021	1021	1023
Tgen2	984	984	986	988	989	989	988	988	992	992	991	991	991	991	989	989
Tgen3	1010	1007	1008	1013	1015	1015	1013	1013	1018	1018	1018	1016	1016	1016	1015	1015
Tgen4	1011	1010	1010	1015	1018	1018	1018	1018	1021	1021	1021	1021	1021	1021	1018	1019
Vquad1	30.7	30.4	30.3	30.4	32.8	32.6	32.5	32.5	34.5	34.5	33.5	33.5	31.4	31.3	30.2	30.3
Vquad2	29.9	29.6	29.5	29.7	32.6	32.3	32.3	32.3	34.8	34.8	33.6	33.6	30.9	30.9	29.6	29.7
Vquad3	30.7	30.4	30.4	30.4	32.9	32.7	32.7	32.7	34.8	34.7	33.7	33.7	31.5	31.5	30.4	30.4
Vquad4	30.6	30.3	30.2	30.3	32.8	32.6	32.6	32.6	34.8	34.8	33.7	33.7	31.5	31.5	30.3	30.3
Vstring min	7.331	7.256	7.229	7.243	8.065	8.021	8.008	8.006	8.71	8.71	8.372	8.372	7.654	7.639	7.258	7.258
Tmin	***	820.3	821.3	820.3	842.5	843.2	841.5	841.2	874.2	873.2	860.8	857.7	833.2	831.4	822.4	822.4
*** Intentionally Blank																

ARPA / SCE AES Generator													
V-I Curve Data @ Tgen SP = 1035 nominal													
											New Pnoz		Bypass Open
Run#	1.0	1.1	2.0	2.1	3.0	3.1	4.0	4.1	5.0	5.1	6.0	6.1	7.0
Date	6/15/95	6/15/95	6/15/95	6/15/95	6/15/95	6/15/95	6/15/95	6/15/95	6/15/95	6/15/95	6/15/95	6/15/95	6/15/95
Time	08:08	08:23	10:14	10:30	11:30	11:43	13:48	14:09	15:05	15:28	17:11	17:26	17:51
PNG (psig)	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	***
Patm (inch Hg)	28.97	28.97	28.97	28.97	28.98	28.98	28.98	28.98	28.98	28.98	28.98	28.98	***
Tamb (deg C)	20.8	20.8	24.5	24.6	23.4	23.2	23.5	22.8	22.5	22.1	20.5	20.4	***
Time (.01 MCF) (sec)	***	808.03	***	732.37	***	902.95	***	1192.02	***	1043.66	***	820.20	***
NGSLPM (Bellows Meter)	***	72.3	***	79.8	***	65.7	***	49.0	***	56.0	***	71.2	***
NGSLPM (MFC measured)	73.1	73.2	80.5	80.4	65.9	65.7	49.5	49.5	56.7	56.6	72.3	72.3	72.3
NGSLPM (MFC set point)	73.5	73.4	80.8	80.7	65.9	65.8	49.6	49.8	57.0	57.0	72.5	72.6	72.8
		72.4	(70.55)	78.9	(76.4)	64.0	(65)	48.1	48.9	56.4	56.3	70.3	(63.7)
Pnoz (measured) (kg/cm^2)	2.07	2.03	2.34	2.28	1.70	1.71	1.14	1.10	1.38	1.42	1.95	1.95	1.76
Pnoz (set point) (kg/cm^2)	1.45	1.47	1.68	1.70	1.25	1.25	0.83	0.83	1.25	1.25	1.76	1.75	1.75
Tnoz (deg C)	28.0	28.1	27.9	27.8	27.7	28.0	27.7	27.5	26.6	26.3	26.7	26.1	***
Tnozx (deg C)	44.6	44.5	44.2	44.0	43.9	44.1	43.3	42.9	42.1	41.7	41.5	41.4	***
Fuel Util (%)	82.5	82.6	82.6	82.6	82.0	81.8	80.9	81.2	81.3	81.7	82.6	82.4	82.3
Air SLPM	3596	3553	3596	3596	3272	3286	2818	2818	3046	3046	3567	3567	3596
Stoichs	6.2	6.2	5.7	5.7	6.4	6.3	7.3	7.3	6.8	6.9	6.2	6.2	6.2
Amps (setpoint)	179.0	179.0	197.0	197.0	160.0	160.0	121.0	121.0	140.0	140.0	179.0	179.0	179.0
Amps (measured)	180.4	180.6	199.1	199.1	161.3	161.3	120.2	120.2	140.5	140.2	180.4	180.6	180.4
Vt (Quad Sum)	122.2	122.4	118.0	118.0	126.6	126.6	135.3	135.0	130.3	130.1	121.0	120.7	122.0
Tgen1	1035	1035	1035	1035	1035	1035	1035	1037	1035	1035	1035	1035	1037
Tgen2	999	999	1000	1000	1002	1002	1004	1006	1002	1002	1000	1000	1002
Tgen3	1027	1027	1027	1027	1029	1029	1032	1034	1032	1032	1032	1032	1034
Tgen4	1029	1029	1027	1027	1030	1030	1034	1035	1035	1035	1034	1034	1034
Vquad1	30.6	30.6	29.6	29.6	31.7	31.7	33.6	33.7	32.5	32.5	30.4	30.3	30.6
Vquad2	30.1	30.1	29.0	29.0	31.5	31.5	33.9	33.9	32.6	32.5	29.8	29.8	30.1
Vquad3	30.8	30.8	29.8	29.8	31.8	31.8	33.8	33.9	32.7	32.6	30.5	30.5	30.7
Vquad4	30.6	30.6	29.6	29.6	31.7	31.7	33.8	33.9	32.6	32.6	30.4	30.4	30.6
Vstring min	7.434	7.434	7.067	7.067	7.786	7.786	8.460	8.475	8.109	8.094	7.317	7.317	7.375
Tmin	832.1	832.6	821.0	820.6	840.1	839.8	869.8	870.8	859.5	858.1	825.9	825.2	824.1
Air Heater %	12	11	0	0	14	13	32	27	24	24	4	3	0
Power kW	22.1	22.1	23.5	23.5	20.4	20.4	18.2	18.3	18.3	18.3	21.8	21.8	22.0
*** Intentionally Blank													

ARPA / SCE AES Generator												
V-I Curve Data @ Tgen SP = 1050 nominal												
Run#	1.0	1.1	2.0	2.1	3.0	3.1	4.0	4.1	5.0	5.1	6.0	6.1
Date	6/14/95	6/14/95	6/14/95	6/14/95	6/14/95	6/14/95	6/14/95	6/14/95	6/14/95	6/14/95	6/14/95	6/14/95
Time	10:19	10:30	12:06	12:16	14:01	15:14	17:13	17:33	18:12	18:31	19:39	19:52
PNG (psig)	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.4
Patm (inch Hg)	29.06	29.06	29.06	29.06	29.08	29.08	29.08	29.08	29.08	29.08	29.08	29.08
Tamb (deg C)	31.2	30.2	30.8	31.0	33.0	31.8	30.7	29.6	28.5	28.0	25.3	24.7
Time (.01 MCF) (sec)	***	806.97	***	727.39	***	906.45	***	1196.26	***	1031.74	***	818.48
NGSLPM (Bellows Meter)	***	72.4	***	80.4	***	64.5	***	48.9	***	56.7	***	71.4
NGSLPM (MFC measured)	73.1	73.3	81.0	81.0	65.5	65.9	49.5	49.6	57.7	57.7	73.0	73.0
NGSLPM (MFC set point)	73.3	73.5	81.4	81.5	65.9	65.7	49.8	49.7	57.7	57.7	73.4	73.4
		72.4		81.5		64.8		48.6		56.2		72.1
Pnoz (measured) (kg/cm^2)	2.01	2.03	2.33	2.38	1.74	1.74	1.11	1.12	1.42	1.41	2.01	2.02
Pnoz (set point) (kg/cm^2)	1.46	1.45	1.71	1.71	1.25	1.26	0.83	0.83	1.04	1.03	1.47	1.45
Tnoz (deg C)	26.6	27.3	27.6	27.7	27.5	27.0	27.4	27.3	27.2	26.7	26.6	26.4
Tnozx (deg C)	***	***	***	***	***	***	44.1	44.2	43.4	43.4	43.0	43.3
Fuel Util (%)	82.4	82.5	82.6	82.7	81.8	82.0	81.2	80.9	81.4	81.6	82.6	82.4
Air SLPM	3596	3596	3610	3625	3299	3272	2818	2806	3072	3046	3596	3581
Stoichs	6.2	6.2	5.7	5.6	6.4	6.4	7.3	7.3	6.8	6.9	6.2	6.2
Amps (setpoint)	179.0	179.0	199.0	199.0	160.0	160.0	121.0	121.0	140.0	140.0	179.0	179.0
Amps (measured)	180.4	180.6	200.9	200.6	160.7	160.7	120.2	120.2	140.5	140.5	180.1	180.4
Vt (Quad Sum)	122.9	122.9	118.4	118.5	127.1	126.8	134.9	134.8	130.9	130.6	122.4	122.5
Tgen1	1051	1051	1051	1051	1051	1051	1052	1051	1051	1051	1051	1051
Tgen2	1013	1013	1013	1013	1013	1011	1018	1016	1015	1015	1011	1013
Tgen3	1041	1041	1043	1043	1045	1045	1049	1049	1049	1048	1046	1046
Tgen4	1045	1045	1043	1043	1046	1046	1051	1051	1051	1049	1048	1049
Vquad1	30.8	30.8	29.8	29.8	31.7	31.7	33.6	33.5	32.6	32.6	30.6	30.6
Vquad2	30.4	30.4	29.1	29.1	31.7	31.6	33.8	33.9	32.8	32.8	30.3	30.3
Vquad3	30.9	30.9	29.8	29.8	31.9	31.8	33.7	33.7	32.8	32.8	30.7	30.8
Vquad4	30.8	30.8	29.8	29.8	31.8	31.7	33.7	33.7	32.8	32.8	30.6	30.7
Vstring min	7.507	7.537	7.141	7.141	7.859	7.859	8.490	8.490	8.211	8.196	7.493	7.522
Tmin	844.6	844.3	830.0	832.1	855.3	854.6	886.2	887.9	875.3	873.6	848.8	848.8
Air Heater %	14	15	0	0	18	19	31	32	28	28	17	14
Power kW	22.2	22.2	23.8	23.8	20.4	20.4	16.2	16.2	18.4	18.4	22.1	22.1
*** Intentionally Blank												

ypass Valve Operational

Run#	1.0	1.1	2.0	2.1	3.0	3.1	4.0	4.1	5.0	5.1	6.0	7.0	7.1	8.0	8.1
Date	6/23/95	6/23/95	6/23/95	6/23/95	6/23/95	6/23/95	6/27/95	6/27/95	6/27/95	6/27/95	6/27/95	6/28/95	6/28/95	6/28/95	6/28/95
Time	14:30	15:00	16:46	17:00	18:00	18:12	13:52	14:00	15:23	16:08	17:24	11:18	11:40	13:28	13:49
Amps (setpoint)							199	199	204	204	213	179	179	139	139
PNG (psig)	40.4	40.4	40.4	40.4	40.4	40.4		40.4		40.4	40.4		40.4		40.4
Palm (inch Hg)	20.06	29.06	29.06	29.06	29.06	29.06		29.12		29.12	29.03		29.08		29.08
Tamb (deg C)	39.7	39.5	37.2	37.0	35.0	35.0		39.5		38.5	37.0		38.0		41.0
Time (.01 MCF) (sec)		737		694.29		915.12		733.3		713.7	683.31		818.4		1041.85
NGSLPM (Bellows Meter)		79.4		84.2		63.9		79.8		82.0	85.6		71.5		56.1
NGSLPM (MFC measured)	80.0	79.8	81.8	85.1	65.3	65.1	80.1	80.1	82.2	82.2	85.6	72.4	72.3	56.6	56.7
NGSLPM (MFC set point)	80.2	80.2	83.6	83.7	64.9	64.9	80.5	80.5	82.5	82.5	86.1	72.8	72.6	56.8	56.8
Pnoz (measured) (kg/cm^2)	2.06	2.06	2.19	2.08	1.53	1.56	2.14	2.14	2.23	2.23	2.39	1.89	1.89	1.36	1.35
Pnoz (set point) (kg/cm^2)	2.03	2.02	2.06	2.20	1.51	1.51	2.12	2.12	2.19	2.19	2.36	1.86	1.86	1.33	1.33
Tnoz (deg C)	30.1	30.1	31.7	31.9	31.6	31.0	29.8	30.1	30.1	31.1	32.0		29.2	29.7	29.7
Pnozy (psig) [0-100]	28	28	28--33	28--34	19--22	19--22	30.0	30.2	30.2	31.0	33.5		27.0	19.6	19.6
Tnozx (deg C)	57.8	57.8	57.0	58.1	58.4	51.2	55.3	55.6	55.6	57.5	59.1		53.9	53.1	53.1
Pnozx (psig) [0-60]	29.0	29.0	29--34	28--34	19--22	19--22	30.0	30.2	30.2	31.0	33.6		26.9	19.8	19.8
Fuel Util (%)	82.6	82.8	82.0	79.1	82.0	82.0	82.6	82.6	82.7	82.7	82.9	82.3	82.7	81.5	81.5
Air SLPM	3654.0	3654.0	3669.0	3698.0	3286.0	3272.0	3640.0	3596.0	3713.0	3742.0	3833.0	3510.0	3467.0	3059.0	3046.0
Stoichs	5.7	5.7	5.5	5.5	6.4	6.4	5.6	5.6	5.6	5.6	5.6	6.0	6.0	6.8	6.8
Amps (setpoint)	198.0	198.0	207.0	207.0	159.0	159.0	199.0	199.0	204.0	204.0	213.0	179.0	179.0	139.0	139.0
Amps (measured)	200.0	200.3	209.1	209.1	160.7	160.4	200.0	200.8	206.2	206.2	215.0	180.9	180.6	139.9	139.9
Vt (Quad Sum)	118.8	119.0	117.4	117.2	128.3	127.1	118.1	118.8	118.0	118.0	116.1	123.2	123.3	132.0	132.0
Tgen1	1049	1051	1051	1051	1049	1049	1051	1050	1049	1051	1051	1049	1049	1051	1049
Tgen2	1015	1015	1015	1013	1015	1013	1015	1013	1013	1013	1013	1013	1013	1015	1013
Tgen3	1030	1030	1029	1029	1030	1032	1030	1030	1029	1029	1027	1034	1034	1038	1038
Tgen4	1041	1041	1038	1037	1040	1040	1043	1041	1038	1038	1037	1046	1045	1048	1048
Vquad1	29.8	29.9	29.3	29.3	32.0	31.9	29.8	29.9	29.7	29.7	29.3	30.9	30.9	33.0	33.0
Vquad2	29.3	29.3	28.7	28.7	32.0	31.7	29.3	29.3	29.0	29.0	28.5	30.6	30.6	33.1	33.1
Vquad3	30.0	30.0	29.6	29.7	32.3	31.9	29.9	30.0	29.8	29.8	29.3	30.9	31.0	33.0	33.0
Vquad4	29.8	29.8	29.4	29.4	32.0	31.9	29.8	29.8	29.5	29.5	29.0	30.8	30.9	32.9	32.9
Vstring min	7.214	7.199	7.009	7.009	7.962	7.918	7.214	7.214	7.126	7.141	7.009	7.581	7.595	8.270	8.284
Tmin	830.0	830.4	827.3	828.0	853.3	853.3	830.7	832.0	830.7	829.0	830.0	840.5	840.5	868.4	868.8
Tairin	538.0	530.0	511.0	512.0	564.0	568.0	520.0	526.0	519.0	518.0	523.0	554.0	555.0	579.0	591.0
Air Heater%	0	0	0	0	12	15	0	0	0	0	0	9	9	20	24
Power kW	23.8	23.8	24.5	24.5	20.6	20.5	23.9	23.9	24.3	24.3	25.0	22.3	22.3	18.5	18.5
RECUPBY%	35.8	35.3	44.9	45.5	15	15	34.2	33.9	37.7	37.9	37.6	15	15	15	15
O:C Quad_1								2.106			2.061		2.075		2.095
O:C Quad_2											2.065		2.086		
O:C Quad_3											2.194		2.219		
O:C Quad_4								2.216			2.205		2.190		2.215
*** Intenionally blank															

V-I Curve Data @ Tgen SP = 1050 nominal with fuel nozzle bypass valve operational

9.0	9.1	10.0	10.1	11.0	11.1	Run#
6/28/95	6/28/95	6/28/95	6/28/95	6/28/95	6/8/95	Date
14:25	14:50	15:44	16:05	17:09	17:38	Time
101.5	101.5	120	120	159	159	Amps (setpoint)
40.4	40.4	40.4	40.4	40.4	40.4	PNG (psig)
29.06	29.08	29.08	29.08	29.08	29.08	Patm (inch Hg)
41.0	41.0	41.0	40.0	35.0	35.0	Tamb (deg C)
	1441.69		1208		914.3	Time (.01 MCF) (sec)
	40.6		48.4		64.0	NGSLPM (Bellows Meter)
41.3	41.3	48.8	48.8	64.8	64.8	NGSLPM (MFC measured)
41.2	41.2	49.1	49.1	64.9	64.9	NGSLPM (MFC set point)
0.84	0.85	1.12	1.12	1.61	1.61	Pnoz (measured) (kg/cm^2)
0.90	0.90	1.10	1.10	1.59	1.59	Pnoz (set point) (kg/cm^2)
30.5	30.5	31.3	31.3	31.3	31.3	Tnoz (deg C)
12.5	12.5	16.2	16.2	16.2	16.2	Pnozy (psig) [0-100]
55.2	55.2	56.1	56.1	56.1	56.1	Tnozx (deg C)
12.8	12.8	16.6	16.6	16.6	16.6	Pnozx (psig) [0-60]
80.1	80.4	80.9	80.9	81.8	82.0	Fuel Util (%)
2501.0	2512.0	2806.0	2800.0	3272.0	3294.0	Air SLPM
7.8	7.8	7.3	7.3	6.4	6.4	Stoichs
101.5	101.5	120.0	120.0	159.0	159.0	Amps (setpoint)
100.0	100.0	119.9	119.6	160.7	160.7	Amps (measured)
138.9	138.7	135.7	135.6	127.6	127.6	Vt (Quad Sum)
1045	1050	1049	1048	1049	1051	Tgen1
1010	1016	1015	1015	1013	1013	Tgen2
1037	1043	1041	1040	1038	1038	Tgen3
1043	1051	1049	1049	1049	1049	Tgen4
34.6	34.5	33.8	33.8	32.0	31.9	Vquad1
35.0	35.0	34.2	34.2	31.8	31.9	Vquad2
34.5	34.5	33.9	33.9	32.0	32.0	Vquad3
34.7	34.6	33.9	33.9	31.9	31.9	Vquad4
8.680	8.680	8.548	8.548	7.962	7.962	Vstring min
887.0	895.0	887.0	887.0	859.0	858.0	Tmin
636.0	617.0	605.0	608.0	575.0	563.0	Tairin
37	32	30	31	19	14	Air Heater%
13.9	13.9	16.2	16.2	20.5	20.5	Power kW
15	15	15	15	15	15	RECUPBY%
	2.157		2.135		2.092	O:C Quad_1
						O:C Quad_2
						O:C Quad_3
	2.235		2.226		2.180	O:C Quad_4
						*** Intenionally blank

	nozzle bypass closed		nozzle bypass active													
Run#	1.0	1.1	2.0	2.1	3.0	3.1	4.0	4.1	5.0	5.1	6.0	6.1	7.0	7.1	8.0	8.1
Date	6/24/95	6/24/95	6/24/95	6/24/95	6/24/95	6/24/95	6/24/95	6/24/95	6/26/95	6/26/95	6/26/95	6/26/95	6/26/95	6/26/95	6/26/95	6/26/95
Time	10:43	11:00	11:58	12:15	13:19	13:40	16:15	16:40	10:41	10:58	13:54	14:16	16:18	16:36	18:00	18:20
Amps (setpoint)	179.0	179.0	179.0	179.0	199.0	199.0	120.0	120.0	180.0	180.0	179.0	179.0	199.0	199.0	159.0	159
PNG (psig)		40.4		40.4		40.4		40.4		40.4		40.4	40.4	40.4		40.4
Patm (inch Hg)		29.02		29.02		29.02		29.02		29.01		29.01	29.01	29.01		29.01
Tamb (deg C)		38.5		40.0		40.0	40.0	39.5		26.0		34.0	33.5	33.0		32.0
Time (.01 MCF) (sec)		812.28		789.31		708.07		1155.53		807.08		817.06	733.43	733.19		887.97
NGSLPM (Bellows Meter)		72.0		74.1		82.6		50.6		72.4		71.5	79.7	79.7		65.8
NGSLPM (MFC measured)	72.3	72.3	72.4	72.3	80.2	80.4	48.8	49.0	72.8	72.7	72.3	72.3	80.1	80.1	64.8	64.7
NGSLPM (MFC set point)	72.8	72.6	72.6	72.6	80.5	80.5	49.0	49.0	73.1	73.1	72.8	72.8	80.5	80.4	64.8	648
Pnoz (measured) (kg/cm^2)	2.05	2.10	1.79	1.78	2.08	2.10	1.03	1.04	2.08	2.08	1.85	1.85	2.15	2.14	1.6	1.6
Pnoz (set point) (kg/cm^2)	1.75	1.75	1.76	1.75	2.05	2.06	1.02	1.02	1.84	1.84	1.82	1.83	2.11	2.1	1.57	1.58
Tnoz (deg C)	27.9	33.8	33.8	34.9	37.1	37.1	38.7	38.7	28.3	28.5	29.1	29.4	30.1	30.2	32.4	32.4
Pnozy(psig) [0-100]*	28.0	28.0	24.5	24.5	28.5	28.5	14.2	14.2	29.0	29.0	25.8	25.5	29.8	30.1	22.3	22.3
Tnozx (deg C)	54.9	51.6	51.6	49.4	47.4	47.4	46.7	46.7	56.6	57.0	55.3	55.5	56.3	56.4	52.1	52.1
Pnozx(psig) [0-60]	29.0	29.0	25.0	24.9	29.5	29.5	15.2	15.2	29.3	29.2	26.2	26.2	30.0	30.1	22.8	22.8
Fuel Util (%)	82.3	82.4	82.4	82.3	82.5	82.6	80.9	80.9	82.4	82.4	82.4	82.0	82.6	82.6	81.9	82.0
Air SLPM	3581	3567	3596	3581	3625	3625	2806	2806	3581	3610	3581	3567	3610	3610	3299	3299
Stoichs	6.2	6.1	6.2	6.2	5.6	5.6	7.3	7.3	6.2	6.2	6.2	6.2	5.6	5.6	6.3	6.4
Amps (setpoint)	179.0	179.0	179.0	179.0	199.0	199.0	120.0	120.0	180.0	180.0	179.0	179.0	199.0	199.0	159.0	159.0
Amps (measured)	180.9	180.6	180.6	180.6	200.9	200.6	119.6	119.6	181.8	181.8	180.6	180.6	200.6	200.6	160.4	160.4
Vt (Quad Sum)	122.1	123.0	124.3	124.6	119.6	119.5	137.8	137.8	122.1	122.1	122.4	122.4	117.3	117.7	128.6	129.0
Tgen1	1035	1035	1035	1035	1035	1037	1035	1034	1035	1035	1035	1037	1037	1034	1034	1034
Tgen2	1000	999	999	999	997	999	1005	1004	1000	1000	1000	1000	1000	999	1002	1000
Tgen3	1019	1019	1016	1016	1013	1013	1019	1018	1021	1019	1018	1018	1016	1013	1016	1016
Tgen4	1030	1027	1027	1028	1023	1023	1029	1027	1029	1029	1027	1027	1026	1023	1026	1026
Vquad1	30.6	30.9	31.2	31.2	30.1	30.0	34.3	34.3	30.7	30.7	30.8	30.8	29.1	29.7	32.2	32.2
Vquad2	30.1	30.4	30.7	30.8	29.3	29.3	34.5	34.5	30.2	30.1	30.3	30.3	29.0	29.0	32.0	32.0
Vquad3	30.7	30.9	31.3	31.4	30.2	30.2	34.5	34.5	30.7	30.6	30.8	30.8	29.8	29.8	32.3	32.5
Vquad4	30.6	30.8	31.2	31.2	30.0	30.0	34.5	34.5	30.6	30.6	30.6	30.6	29.5	29.4	32.1	32.3
Vstring min	7.449	7.493	7.566	7.581	7.155	7.155	8.622	8.622	7.463	7.463	7.478	7.478	7.097	7.082	7.918	7.947
Tmin	833.5	832.1	832.8	834.6	822.7	822.0	873.2	873.2	833.2	832.5	833.2	833.5	822.0	819.6	839.4	839.4
Tairin	556.0	556.0	550.0	552.0	512.0	502.0	582.0	587.0	556.0	558.0	551.0	540.0	504.0	515	559	563
Air Heater %	9	10	6	6	0	0	20	23	9	9	8	5	0	0	13	13
Power kW	22.1	22.3	22.4	22.5	24.0	24.0	16.0	16.5	22.2	22.2	22.2	22.2	23.6	23.6	20.6	20.7
RECUPBY%	15.0	15.0	15.0	15.0	39.3	42.1	15.0	15.0	15.0	15.0	15.0	15.0	37.6	35.4	15.0	15.0
O:C Quad_1		2.262		2.034		2.001		2.073		2.145		2.104		2.078		2.067
O:C Quad_2																
O:C Quad_3																
O:C Quad_4		2.313		2.131		2.095		2.127		2.290		2.235		2.215		2.153
*** Intentionally Blank																

Run#	1.0	2.0	2.1	3.0	4.0	4.1	5.0	5.1	6.0	6.1	7.0	7.1	8.0	8.1	9.0	9.1	10.0
Date	6/21/95	6/21/95	6/21/95	6/21/95	6/22/95	6/22/95	6/22/95	6/22/95	6/22/95	6/22/95	6/23/95	6/23/95	6/28/95	6/28/95	6/29/95	6/29/95	6/29/95
Time	08:06	10:48	11:03	18:08	08:30	08:50	15:16	15:24	17:37	17:57	8:30	8:56	18.57	19:17	9:02	9:21	11:49
Amps (setpoint)	159	159	159	179	179	179	179	179	179	179	179	179	159	159	179	179	195.5
PNG (psig)	40.4	***	40.4	40.4	40.4	40.4	***	40.2	40.4	40.4		40.4		40.4	40.4	40.4	40.4
Patm (inch Hg)	29.06	***	29.06	29.03	29.08	29.08	***	29.08	29.05	29.05		29.1		29.08	29.18	29.18	29.18
Tamb (deg C)	22.0	***	33.5	30.0	27.0	28.0	***	37.0	34.0	34.0		30.5		33.0	23.0	23.0	34.0
Time (.01 MCF) (sec)	926.95	***	925.00	798.63	***	819.37	***	820.75		815.37		820.53		916.85		818.2	
NGSLPM (Bellows Meter)	63.1	***	63.2	73.2	***	71.4	***	71.0		71.7		71.3		63.8		71.6	
NGSLPM (MFC measured)	64.5	64.5	64.4	72.3	72.3	72.4	72.4	72.3	72.4	72.4	72.2	72.3	64.7	64.7	72.3	72.3	78.9
NGSLPM (MFC set point)	64.7	64.7	65.8	72.8	72.5	72.8	72.8	72.5	72.5	72.8	72.6	72.8	64.9	64.9	72.8	72.6	79.1
Pnoz (measured) (kg/cm^2)	1.67	1.73	1.73	2.16	1.98	1.99	2.06	2.06	1.78	1.77	1.79	1.78	1.61	1.61	1.89	1.89	2.14
Pnoz (set point) (kg/cm^2)	1.49	1.50	1.49	1.76	1.76	1.76	1.76	1.76	1.75	1.75	1.76	1.75	1.59	1.59	1.86	1.86	2.10
Tnoz (deg C)	27.8	27.9	28.1	34.1	27.9	28.1	29.7	29.6	31.5	31.3	27.6	27.6	31.5	31.4	28.0	28.0	29.5
Pnozy (psig) [0 - 100] *	***	24.0	24.0	30.0	27.0	27.5	28.0	28.0	24.5	24.5	25.0	25.0	22.0	22.0	26.8	26.8	29.7
Tnozx (deg C)	42.5	51.4	52.8	48.5	42.5	42.7	59.3	59.3	57.6	57.8	43.4	43.4	57.1	57.2	40.6	40.6	54.5
Pnozx (psig) [0 - 60] *	***	24.5	24.3	30.2	28.0	27.9	29.0	29.0	25.1	25.0	25.0	25.0	23.0	23.0	26.9	26.9	30.0
Fuel Util (%)	82.0	81.9	81.9	82.4	82.6	82.3	82.4	82.3	82.4	82.6	82.3	82.6	82.0	81.8	82.6	82.6	82.7
Air SLPM	3286	3258	3258	3596	3596	3596	3581	3581	3596	3596	3596	3596	3286	3286	3467	3467	3610
Stoichs	6.4	6.4	6.4	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.4	6.4	6.0	6.0	5.7
Amps (setpoint)	159.0	159.0	159.0	179.0	179.0	179.0	179.0	179.0	179.0	179.0	179.0	179.0	159.0	159.0	179.0	179.0	195.5
Amps (measured)	160.4	160.4	160.1	180.6	180.6	180.4	180.4	180.9	180.9	180.9	180.9	180.4	160.7	160.4	180.4	180.4	197.4
Vt (Quad Sum)	125.3	125.4	125.2	122.4	121.2	121.3	121.2	121.1	121.2	121.4	121	121.4	126.4	126.3	121.6	121.7	117.5
Tgen1	1021	1021	1019	1021	1019	1019	1019	1021	1019	1019	1021	1019	1021	1021	1019	1019	1019
Tgen2	992	991	991	988	992	992	989	989	988	989	991	992	988	988	992	992	988
Tgen3	970	1005	1005	1000	1005	1005	1002	1002	999	1000	1004	1004	1008	1008	1007	1007	1002
Tgen4	1019	1019	1018	1013	1018	1018	1013	1013	1011	1011	1016	1016	1018	1018	1018	1018	1011
Vquad1	31.9	31.5	31.5	30.8	30.4	30.4	30.6	30.5	30.5	30.6	30.4	30.4	31.7	31.7	30.6	30.6	29.6
Vquad2	31.1	31.0	31.0	30.1	29.9	29.9	29.8	29.8	29.8	29.9	29.8	29.9	31.3	31.3	30.1	30.1	28.8
Vquad3	31.5	31.5	31.4	30.8	30.5	30.6	30.4	30.4	30.6	30.6	30.5	30.6	31.8	31.7	30.6	30.6	29.7
Vquad4	31.4	31.5	31.4	30.7	30.5	30.4	30.2	30.3	30.3	30.4	30.4	30.4	31.6	31.5	30.4	30.4	29.3
Vstring min	7.669	7.654	7.630	7.375	7.317	7.331	7.317	7.317	7.317	7.331	7.317	7.331	7.757	7.742	7.361	7.375	7.038
Tmin	824.8	824.1	824.1	816.5	819.3	819.6	818.6	818.6	819.9	819.9	819.3	819.6	831.4	831.1	818.0	818.0	810.0
Tairin	552	547	555	551	552	550	550	548	544.0	540.0	540.0	547.0	544.0	540.0	538.0	535.0	512.0
Air Heater %	13	11	14	6	9	9	8	8	5	4	6	9	8	7	7	6	0
Power kW	20.1	20.1	20.0	22.1	21.9	22.0	21.9	21.8	21.9	22	21.9	21.9	20.3	20.3	22	22	23.2
RECUPBY%													15	15	15	15	40.4
O:C Quad_1														2.089		2.104	
O:C Quad_2																	
O:C Quad_3																	
O:C Quad_4														2.182		2.192	

*** Intentionally Blank

* Entries not corrected for calibration

V-I Curve Data @ Tgen SP = 1020 nominal

Run#	10.1	11.0	11.1	12.0	12.1	13.0	13.1
Date	6/29/95	6/29/95	6/29/95	6/29/95	6/29/95		
Time	12:08	13:49	2:52	16:50	17:02		
Amps (setpoint)	195.5	158.5	158.5	120.5	120.5		
PNG (psig)	40.4	40.4	40.4	40.4	40.4		
Patm (inch Hg)	29.18	29.03	29.03	29.03	29.03		
Tamb (deg C)	34.0	36.0	37.0	34.0	34.0		
Time (.01 MCF) (sec)	746.2		920		1148		
NGSLPM (Bellows Meter)	78.5		63.5		50.9		
NGSLPM (MFC measured)	78.9	64.5	64.5	49.2	49.2		
NGSLPM (MFC set point)	79.2	64.7	64.7	49.2	49.2		
Pnoz (measured) (kg/cm^2)	2.13	1.61	1.61	1.13	1.13		
Pnoz (set point) (kg/cm^2)	2.10	1.58	1.58	1.11	1.11		
Tnoz (deg C)	29.6	29.9	29.9	36.6	36.6		
Pnozy (psig) [0 - 100] *	30.0	23.0	23.0	16.2	16.2		
Tnozx (deg C)	54.4	55.3	55.3	48.1	48.1		
Pnozx (psig) [0 - 60] *	30.0	23.0	23.0	16.6	16.6		
Fuel Util (%)	82.7	81.7	81.9	81.0	80.8		
Air SLPM	3596	3299	3258	2831	2818		
Stoichs	5.7	6.4	6.4	7.3	7.3		
Amps (setpoint)	195.5	158.5	158.5	120.5	120.5		
Amps (measured)	197.7	160.1	160.1	120.2	120.2		
Vt (Quad Sum)	117.6	126.5	126.5	137.5	137.5		
Tgen1	1021	1021	1021	1019	1021		
Tgen2	989	991	989	989	989		
Tgen3	1002	1004	1004	1005	1005		
Tgen4	1011	1016	1016	1018	1018		
Vquad1	29.7	31.7	31.7	34.3	34.2		
Vquad2	28.9	31.4	31.4	34.4	34.4		
Vquad3	29.7	31.8	31.8	34.5	34.5		
Vquad4	29.3	31.6	31.6	34.4	34.4		
Vstring min	7.038	7.757	7.757	8.576	8.578		
Tmin	810.0	828.0	828.0	857.0	858.0		
Tairin	506.0	544.0	547.0	584.0	578.0		
Air Heater %	0	9	12	24	22		
Power kW	23.2	20.3	20.3	16.5	16.5		
RECUPBY%	41.7	15	15	15	15		
O:C Quad_1	2.056		2.108		2.023		
O:C Quad_2	2.057		2.098		2.003		
O:C Quad_3	2.195		2.238		2.142		
O:C Quad_4	2.183		2.219		2.083		
*** Intentionally Blank							
* Entries not corrected for ca							

Run#			
Date			
Time			
Amps (setpoint)			
PNG (psig)			
Patm (inch Hg)			
Tamb (deg C)			
Time (.01 MCF) (sec)			
NGSLPM (Bellows Meter)			
NGSLPM (MFC measured)			
NGSLPM (MFC set point)			
Pnoz (measured) (kg/cm^2)			
Pnoz (set point) (kg/cm^2)			
Tnoz (deg C)			
Pnozy (psig) [0 - 100] *			
Tnozx (deg C)			
Pnozx (psig) [0 - 60] *			
Fuel Util (%)			
Air SLPM			
Stoichs			
Amps (setpoint)			
Amps (measured)			
Vt (Quad Sum)			
Tgen1			
Tgen2			
Tgen3			
Tgen4			
Vquad1			
Vquad2			
Vquad3			
Vquad4			
Vstring min			
Tmin			
Tairin			
Air Heater %			
Power kW			
RECUPBY%			

APPENDIX B — V-I TEST RECORDED DATA

TEST DATES: October 3-4, 1995

FUEL: Jet Fuel Reformate

V-I Testing on Gasified Jet Fuel

				Morn. Steady State									
Run #		1	2	X	--	3	4	5	6	7	8	9	10
Date		10/3/95	10/3/95	10/4/95	10/4/95	10/4/95	10/4/95	10/4/95	10/4/95	10/4/95	10/5/95	10/5/95	10/5/95
Time		15:24	16:47	8:00	8:30	10:36	12:06	14:45	15:56	16:20	9:16	10:45	13:54
Amps (set)		167	186	186		186	206	222	198	178	158.5	138.7	138.7
Amps (meas)		170.7	190	190		190.3	210.3	226.7	199.7	179.8	160.1	139.9	139.9
LF (bellows meter)	slpm	119.8	133.4	129.85		129.2	142.2	153.8	135.8	121.7	108.9	96.7	96.6
LF (MFC meas)	slpm	115.0	127.7	123.3		127.6	140.8	151.6	134.0	121.0	108.1	95.3	95.1
LF (MFC setpt)	slpm	115.2	127.8	123.5		127.8	141.0	151.7	134.1	121.0	108.4	95.2	95.2
Pnoz (meas)	kg/cm^2	2.40	2.78	2.39		2.78	3.2	3.56	2.99	2.57	2.21	1.83	1.82
Pnoz (set pt)	kg/cm^2	2.38	2.76	2.37		2.76	3.19	3.54	2.96	2.55	2.18	1.82	1.82
Fuel Utilization	%	82	82	85		82	82	82	82	82	82	82	82
Air Flow	slpm	3382	3538	3538		3553	3758	3848	3581	3467	3272	3046	3072
Stoichs		6.2	5.8	5.8		5.8	5.6	5.3	5.7	6.0	6.4	6.8	6.9
VT	volts	127.6	122.7	121.4		122.9	118.4	115.5	122.2	126.3	130.3	133.7	134.0
Tgen1	°C	1019	1021	1021		1035	1035	1049	1049	1045	1049	1035	1021
Tgen2	°C	984	986	984		997	997	1011	1010	1005	1008	996	984
Tgen3	°C	1000	999	999		1011	1010	1023	1023	1019	1026	1016	1004
Tgen4	°C	1015	1011	1011		1023	1021	1030	1032	1027	1037	1026	1015
Vquad1	volts	32.0	30.9	30.6		30.9	29.8	29.2	30.7	31.7	32.6	33.4	33.5
Vquad2	volts	31.7	30.4	30.1		30.6	29.3	28.6	30.5	31.6	32.7	33.6	33.6
Vquad3	volts	32.0	30.8	30.4		30.8	29.7	28.9	30.6	31.6	32.6	33.4	33.5
Vquad4	volts	32.0	30.7	30.4		30.6	29.5	28.8	30.4	31.5	32.5	33.4	33.4
Vstring (min)	volts	7.903	7.551	7.493		7.654	7.302	7.141	7.625	7.918	8.211	8.431	8.402
Tmin	°C	837	831	822		837	830	832	842	856	865	864	852
Tair (in)	°C	524	493	496		515	498	486	512	542	556	567	552
Air Heater	%	0	0	0		0	0	0	0	0	10	16	12
Power	kWe	21.8	23.3	23.1		23.3	24.9	26.2	24.4	22.7	20.9	18.7	18.7
Recupby	%	22.7	35.7	33.9		34.7	39	43.8	36.6	28	15	15	15

APPENDIX C — V-I TEST RECORDED DATA

TEST DATES: February 15-16, 1996

FUEL: Diesel Fuel Reformate

V-I Testing on Gasified Diesel Fuel

Run #		1	2	3	4	5	6
Date		2/15/96	2/15/96	2/15/96	2/15/96	2/16/95	2/16/95
Time		7:39	14:58	12:45	9:57	10:00	12:25
Amps (set)		180	140	160	180	200	220
Amps (meas)		179.8	138.4	159.5	180.4	200.1	220.5
LF (bellows meter)	slpm	120.4	93.2	106.9	120.4	134.9	149
LF (meas)	slpm	121.0	94.3	107.7	121.2	134.6	147.4
LF (set pt)	slpm	121.2	94.3	108	121.3	134.7	147.7
Pnoz (meas)	kg/cm^2	2.58	1.81	2.19	2.58	2.99	3.42
Pnoz (set pt)	kg/cm^2	2.56	1.80	2.17	2.56	2.98	3.41
Fuel Utilization	%	82	82	82	82	82.4	82.7
Air Flow	slpm	3439	3072	3259	3467	3640	3728
Air Stoichs		6.1	6.8	6.4	6.0	5.6	5.3
VT	volts	122.4	131.2	126.8	123.2	118.3	114.6
Tgen1	°C	1002	1010	1013	1016	1021	1037
Tgen2	°C	969	973	976	981	984	999
Tgen3	°C	1019	1035	1035	1035	1035	1049
Tgen4	°C	992	1002	1004	1005	1007	1018
Vquad1	volts	30.7	32.8	31.7	30.9	29.7	28.8
Vquad2	volts	30.5	33	31.8	30.8	29.5	28.5
Vquad3	volts	30.6	32.6	31.6	30.8	29.6	28.7
Vquad4	volts	30.5	32.8	31.7	30.7	29.5	28.5
Vstring (min)	volts	7.67	8.21	8.01	7.83	7.42	7.21
Tmin	°C	820	842	835	832	826	833
Tair (in)	°C	518	564	546	531	564	495
Air Heater	%	0	16.6	10	0	0	0
Power	kWe	22	18.2	20.3	22.2	23.7	25.3
Recupby	%	23.9	15.0	15.0	21.8	26.1	30.4

APPENDIX D — V-I TEST RECORDED DATA

TEST DATES: February 22, 23, 26, 1996

Fuel: Local Natural Gas

V-I Testing on Local Natural Gas

Run #		1	2	3	4	5	6	7	8	9	10
Date		2/26/95	2/23/96	2/23/96	2/23/96	2/23/96	2/23/96	2/22/96	2/22/96	2/22/96	2/23/96
Time		8:06	15:00	13:07	12:25	10:17	7:50	15:07	12:44	9:48	7:50
Amps (set)		180	180	210	200	200	180	140	160	160	180
Amps (meas)		180.4	180.4	210	200	200	179.8	138.1	158.9	158.9	179.8
LF (bellows meter)	slpm	71.4	71.7	83.3	79.3	79.6	71.5	55.3	63	63.1	71.5
LF (MFC meas)	slpm	72.2	72.3	83.7	79.8	79.7	71.9	56.0	64.1	61.1	71.9
LF (MFC setpt)	slpm	72.4	72.5	83.9	80.2	80.2	72.3	56.2	64.2	64.2	72.3
Pnoz (meas)	kg/cm^2	1.85	1.88	2.28	2.13	2.16	1.87	1.31	1.56	1.55	1.87
Pnoz (set pt)	kg/cm^2	1.85	1.85	2.28	2.14	2.14	1.85	1.31	1.57	1.57	1.85
Fuel Utilization	%	82.3	82.3	82.7	82.7	82.7	82.5	81.6	81.8	81.8	82.5
Air Flow	slpm	3654	3538	3684	3640	3669	3654	3046	3341	3327	3654
Stoichs		6.3	6.1	5.5	5.6	5.7	6.3	6.8	6.5	6.5	6.3
VT	volts	119	121.8	114.6	116.6	117.7	122.2	130.6	124.7	123.4	122.2
Tgen1	°C	988	1015	1016	1016	1008	1005	996	999	983	1005
Tgen2	°C	956	978	980	980	973	970	961	965	951	970
Tgen3	°C	1019	1049	1049	1049	1035	1035	1034	1035	1021	1035
Tgen4	°C	988	1011	1011	1011	1004	1002	994	997	983	1002
Vquad1	volts	29.9	30.6	28.8	29.3	29.6	30.6	32.6	31.2	30.9	30.6
Vquad2	volts	29.5	30.5	28.3	29.0	29.1	30.4	32.7	31.2	30.6	30.4
Vquad3	volts	29.7	30.4	28.7	29.1	29.5	30.5	32.5	31.0	30.8	30.5
Vquad4	volts	29.8	30.6	28.7	29.3	29.6	30.6	32.8	31.3	31.0	30.6
Vstring (min)	volts	7.39	7.65	7.11	7.27	7.30	7.62	8.20	7.80	7.67	7.62
Tmin	°C	826	820	806	809	807	817	822	814	795	817
Tair (in)	°C	542	549	507	519	519	549	568	551	533	554
Air Heater	%	14	13.9	0	0	0	12.6	23.7	17.5	13.6	12.6
Power	kWe	21.4	22	24	23.3	23.5	22	18.1	19.8	19.6	22
Recupby	%	15	15	21.4	19.4	21.8	15	15	15	15	15

APPENDIX E — HALDOR TOPSOE, INC.

30 KW LFP DESIGN AND OPERATIONS REPORT

EXECUTIVE SUMMARY

HTI process and mechanical engineers designed the 32 kW brassboard fuel processor. The basic operating conditions were found during bench scale testing conducted at the HTAS offices in Lyngby, Denmark. Utilizing this information, HTI developed the Basic Engineering Package. This package was then used by the selected fabricator (Texas Systems and Controls, Inc. of Houston, Texas) to complete the design and construction of the logistic fuel processor. These functions occurred from December 1994 to May 1995.

Once fabricated, the fuel processor was installed at the SOFC test facilities of Southern California Edison in Grand Terrance, California from June through August 1995. The installation and commissioning period included work to provide utilities and feedstock to the unit, set up the control system, tie into the SOFC fuel supply system, leak testing, and mechanical shakedown. Several problems with the electric heaters of the unit were uncovered and rectified.

On August 24 , 1995, a methane rich stream, derived from commercial grade JP-8 and processed by the fuel processor, was delivered to the SOFC. The fuel processor met operating conditions, but was limited to a maximum flow rate of approximately 70% of design capacities due to electric heater limitations. Additional heater capacity was added, and the unit completed 766 hours delivering jet fuel reformate to the SOFC on October 11, 1995. During the run on jet fuel, the feed was desulfurized to less than 1 ppm (wt). Inlet sulfur concentration was 80 ppm (wt). Initially, the unit processed 5.3 kg/hr jet fuel, utilizing a hydrogen to fuel ratio of 0.5: 1, and a steam to hydrocarbon ratio of 2.5:1. Reformate composition was nearly identical to the design basis, with a stream of approximately 50 % methane (dry basis) delivered. The SOFC operated at 26.2 kW.

When the jet fuel supply was nearly exhausted, diesel fuel was added and the unit continued operating. From October through February 1996, the fuel processor achieved the requisite 1500 hours delivering fuel to the SOFC. However, during this period, the fuel processor was available or operating for approximately 2880 hours, achieving an on-line factor of 75 %. Again, the fuel processor met the goals of the established test program. Exit sulfur levels remained low enough to prevent significant deactivation of the prereforming catalyst via sulfur deactivation.

Reformate composition did not vary between the jet fuel test and the diesel test. Design flow rates of 5.3 kg / hr were achieved as necessary.

In summary, the brassboard fuel processor achieved all goals set forth at the outset of the ARPA program. Design flow rates were achieved, and combined SOFC/fuel processor operating hours were accumulated. One stage deep desulfurization was achieved to provide minimal poisoning of the downstream prereforming catalyst. Both jet fuel and diesel fuel were adiabatically prereformed into a methane rich synthesis gas, without significant carbon deposition or degradation of the prereforming catalyst. The SOFC operated satisfactory on the reformate fuel.

INTRODUCTION AND GOALS

Haldor Topsoe Inc. (HTI), as part of a sub-contract with Westinghouse Electric Corporation (WEC), designed and constructed a fuel processor to provide a methane rich fuel gas stream from logistic (diesel or jet) fuels. This fuel processor was then operated to provide fuel for the solid oxide fuel cell to confirm the long term operability of the combined unit.

The purpose of this report is to document the design, operation, and post-operational analysis of the brassboard fuel processor test. The report will review the goals of the program, the process and mechanical design, the operation of the unit, the analysis of the used catalyst, and information that was learned and can be later applied to the design of a mega-watt class fuel processor.

HTI is acting as a subcontractor to WEC. The program is being administered by NASA's Lewis Research Center in Cleveland, Ohio. Funding for the project is provided by the United States government, Advanced Research Projects Agency (ARPA).

GOALS

The goals established for the brassboard (32 kW) testing program were as follows:

1. Utilize the operating conditions derived during the laboratory (bench scale) testing as design basis for the brassboard tests.
2. Demonstrate desulfurization of jet fuel and diesel from an inlet concentration of 0.3% wt. to approximately 1 ppm (wt) total sulfur to prevent excessive poisoning of the prereforming catalyst.

3. Demonstrate adiabatic prereforming of jet fuel and diesel into a methane rich synthesis gas appropriate for use in the solid oxide fuel cell.

4. Operate the combined unit (fuel processor and solid oxide fuel cell) on jet fuel and diesel for 2000 hours (500 hours minimum on jet fuel and 1500 hours on diesel).

PROCESS DESCRIPTION

Introduction

The following is a description of the processes used to convert raw diesel feed into a methane product which can be utilized in a solid oxide fuel cell.

Desulfurization

The catalysts employed for the steam reforming process are extremely sensitive to sulfur compounds since these will cause deactivation. Since most hydrocarbon feedstocks will normally contain appreciable amount of sulfur-bearing compounds, the sulfur must be removed before the steam reforming. This is accomplished in the desulfurization section.

The continuous leakage of sulfur to the reformer from all sources should preferable be less than 1 ppm by weight relative to the diesel feed. The required adiabatic prereforming catalyst volume is to a large extent proportional to the sulfur concentration in the desulfurized feedstock. The sulfur present in the feedstock will be quantitatively absorbed on the catalyst.

The desulfurization unit contains three reactors, a reactor loaded with nickel-molybdenum-oxide hydrogenation catalyst followed by two reactors containing zinc-oxide sulfur absorption catalyst.

The first reaction in the desulfurization system is catalyzed by a nickel-molybdenum hydrogenation catalyst in a single hydrogenation bed. The recommended Topsoe catalyst TK-525 has a bulk density of about 0.72 kg/l.

The catalyst is delivered as 1.6 mm to 3.2 mm cylinders.

It catalyzes the following reactions occur:

$$RSH + H_2 \rightarrow RH + H_2S$$

$$R_1SSR_2 + 3H2 \rightarrow R_1H + R_2H + 2H_2S$$

$$R_1SR_2 + 2H_2 \rightarrow R_1H + R_2H + H_2S$$
$$COS + H_2 \rightarrow CO + H_2S$$

where R is a radical of hydrocarbon.

As shown in the Process Flow Diagram, 65036-FD-011, the feed is a diesel (or jet fuel) and hydrogen mixture beginning with raw fuel flow of 6.21 kg/h which is pumped from tank T-101. The pump increases the pressure from 1 to 50 bar. Hydrogen from tank T-102 is mixed with the high pressure diesel at a rate of 0.28 kg/hr. The mixture is heated from ambient to 370°C immediately before entering the reactor. The reactor contains about 8 liters of TK-525 catalyst.

Having passed over the hydrogenation catalyst in the first reactor, the hydrogen sulfide is absorbed in the second and third reactor in this section - R-102 A/B.

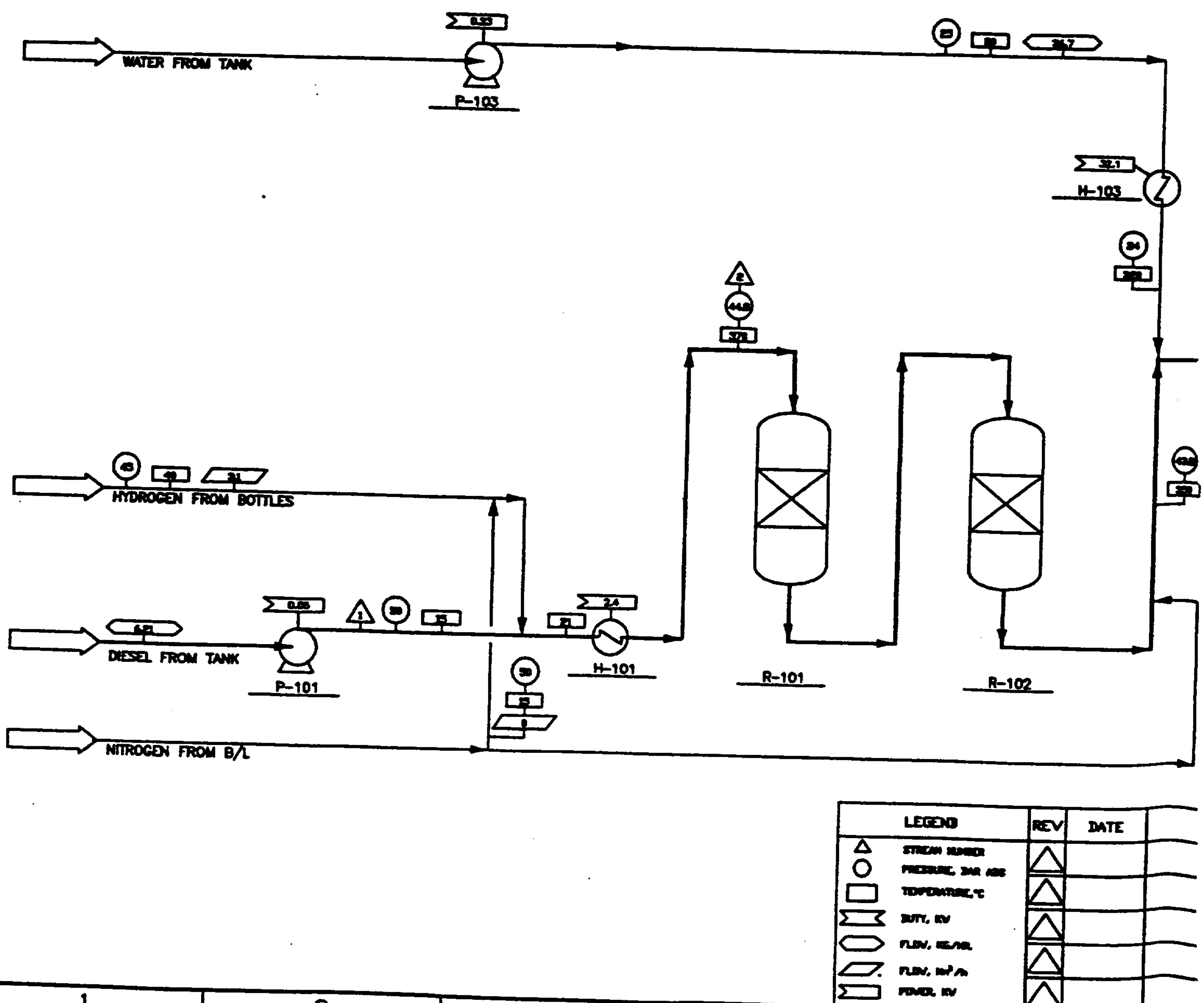
The two reactors situated in series are identical. Two reactors were required to meet height restrictions. Each of the two reactors is loaded with about 140 liter of Topsoe sulfur absorption catalyst HTZ-3 which is delivered in 3 mm cylindrical extrudates. The bulk density is approximately 1.35 kg/l. The zinc oxide reacts with the H_2S according to the following equation:

$$H_2S + ZnO \leftarrow ZnS + H_2O$$

During normal operation, the sulfur content of the feedstock in contact with the zinc oxide catalyst is reduced according to the equilibrium constant:

$$H_2S/H_2O = 1.3 \times 10^{-6}$$

STREAM NO.		1		2		3		4		5		6	
DESCRIPTION		RAW DIESEL		INLET DESULFURIZER						PRODUCT TO SOFC			
COMPONENT	MOL WT	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %
HYDROGEN	2.016			.1386	83.05					0.2780	38.54		
CARBON MONOXIDE	28.011									0.0049	0.67		
CARBON DIOXIDE	44.010									0.1432	19.84		
METHANE	16.043									0.2954	40.95		
DIESEL	220	0.0283	100.00	0.0283	16.95					0	0.00		
TOTAL (DRY)		0.0283	100.00	0.1669	100.00		100.00		100.00	0.7215	100.00		100.00
WATER K MOL./HR.		0.		0						0.0022			
TOTAL K MOL/HR (WET)		0.0283		0.1669						0.7237			
TOTAL KG/HR.			6.21		6.49						11.78		
AVG. MOL. WT.			220		38.90						16.27		
PRESSURE, BAR ABS			50.0		44.8						20.9		
TEMPERATURE, DEG. C			15.		370						40		



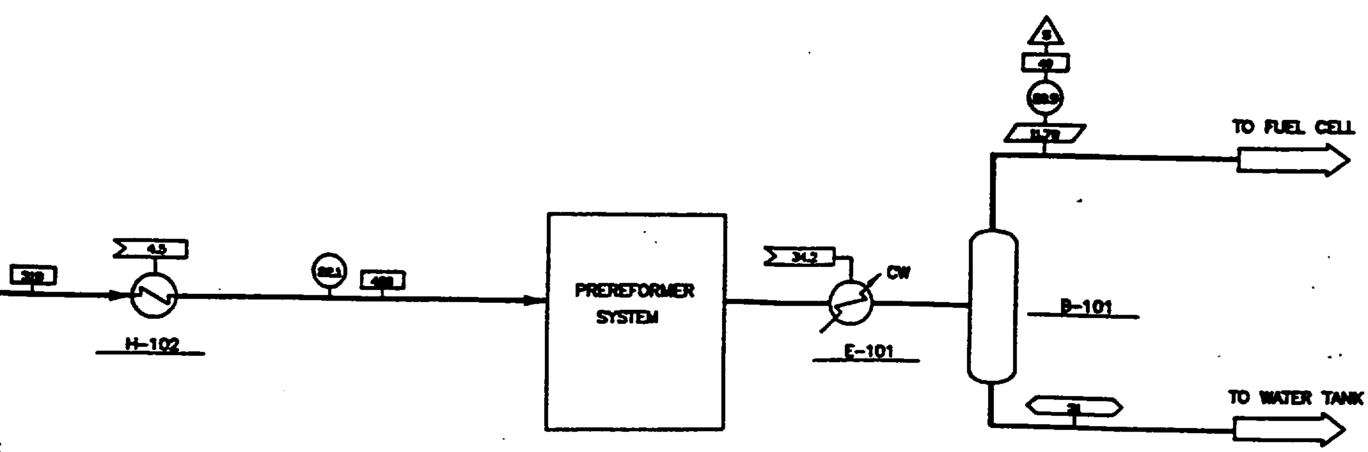
MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %
100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00

A

B

C

D



E

F

DESCRIPTION	DRAWN	CHECKED	DRAWN BY	AGP	9/26/97	CONFIDENTIAL
			CHECKED			
			PROCESS APPROVED			
			PROCESS MGR APPROVED			
			PROJ MGR APPROVED			
			CLIENT APPROVED			

HALDOR TOPSOE, INC.
HOUSTON, TEXAS

VESTINGHOUSE ELECTRIC CORP.
32KW SOFC BRASS BOARD

PROCESS FLOW DIAGRAM

SCALE: NONE
DRAWING NUMBER: 65036-FD-011
REV.

G

6 7 8 9 10

Prereforming

Steam at a rate of 20.6 kg/hr is added to the gaseous mixture of feed fuel and hydrogen from the desulfurization section, and the resultant mixture is sent to the prereforming unit. Decomposition of hydrocarbons take place over nickel catalyst by reaction with steam.

The steam reforming of hydrocarbons can be described by the following reactions:

(1)	$C_nH_m + nH_2O$	$\rightarrow$	$nCO + (n + m/2)$ H2
(2)	$CH_4 + H_2O$	$\leftarrow$	$CO + 3H_2$
(3)	$CO + H_2O$	$\leftarrow$	$CO_2 + H_2$

Reactions (1) and (2) are endothermic while reaction (3) is exothermic.

In the operation of the prereformer system, carbon formation outside and/or inside the catalyst particles is possible. Carbon deposits outside the particles will increase the pressure drop over the catalyst bed, and deposits inside the particles may reduce their mechanical strength and activity.

In the prereformer, carbon formation is thermodynamically not possible under the conditions foreseen if equilibrium is obtained for each step. However, if the catalyst is deactivated, for instance by sulfur, it will lose its activity and carbon formation may occur.

At significantly lower than actual steam to carbon ratios, there will be a thermodynamic possibility of carbon formation which would result in carbon lay-down, especially inside the catalyst particles.

The steam is mixed with the diesel/hydrogen stream from the desulfurization section, and the mixed fluid is preheated to 480 EC in an electric heater, H-102. Using about 50 liters of the Topsoe RKNGR catalyst, the reformer decomposes the higher hydrocarbons into hydrogen, carbon monoxide, carbon dioxide, and methane corresponding to reaction schemes (1), (2), and (3).

The RKNGR catalyst is specially treated for low temperature reforming operation. The catalyst size is 4.5 x 4.5 mm with a bulk density of 1.35 kg/l. The RKNGR catalyst, as supplied, is prereduced. It is not pyrophoric at temperatures below 60°C. It may be handled without any difficulties in atmospheric air during loading of catalyst.

RKNGR needs no special activation at start-up of the unit, but great care should be taken to always maintain a reducing atmosphere in order to avoid oxidation of the catalyst which would necessitate a reactivation or replacement of the catalyst.

The reduced RKNGR catalyst is active above a temperature of 400°C, and it is stable at temperatures well in excess of the maximum obtained during normal operation. The decrease in activity will, under normal operation and reducing conditions, be a slow process. The catalyst may, however, be deactivated by a variety of compounds that may be introduced with the process feed or the steam.

The lower the sulfur content, the better the catalyst will retain its activity.

As the feed to R-103 will always contain minor amounts of sulfur, a progressive deactivation of the catalyst during the lifetime will be experienced.

If the steam to carbon ratio drops to very low levels, and especially if the steam flow should stop completely, even for some seconds, a heavy carbon lay-down would be expected.

If the catalyst is exposed to steam alone, it will be oxidized and must be reactivated at the next start-up. Reactivation of the RKNGR catalyst may be carried out in a hydrogen rich stream at the same temperature at which it was oxidized.

Product Separation

The methane rich stream exiting the prereformer unit is cooled to about 40°C in the aircooler, E-101, and condensed water is removed in the separator, E-101. The water is stored in a water tank and the gas from B-101 forms the feed to the SOFC unit. The fuel cell feed gas make-up composition is about 50% CH_4, 31% H_2, 19% CO_2 and 1% CO.

Process Control Scheme

The hydrogenation, desulfurization, and prereforming units are designed to operate adiabatically. For such small units, the heat loss is relatively high, and may, therefore, influence the adiabatic reaction. In order to compensate for this heat loss, a heating panel is installed between two layers of insulation surrounding each of the reactors. Each reactor is surrounded by a minimum of four sections of the insulation and heating materials, thereby creating four zones. Each zone contains two thermocouples. One is located on the surface of the reactor, and the second is located next to the heating panel. The thermocouples are attached to a temperature differential indicator which signals the control panel to adjust the heat added to the zone.

MECHANICAL DESCRIPTION

Hydrogenation and Desulfurization

P-101

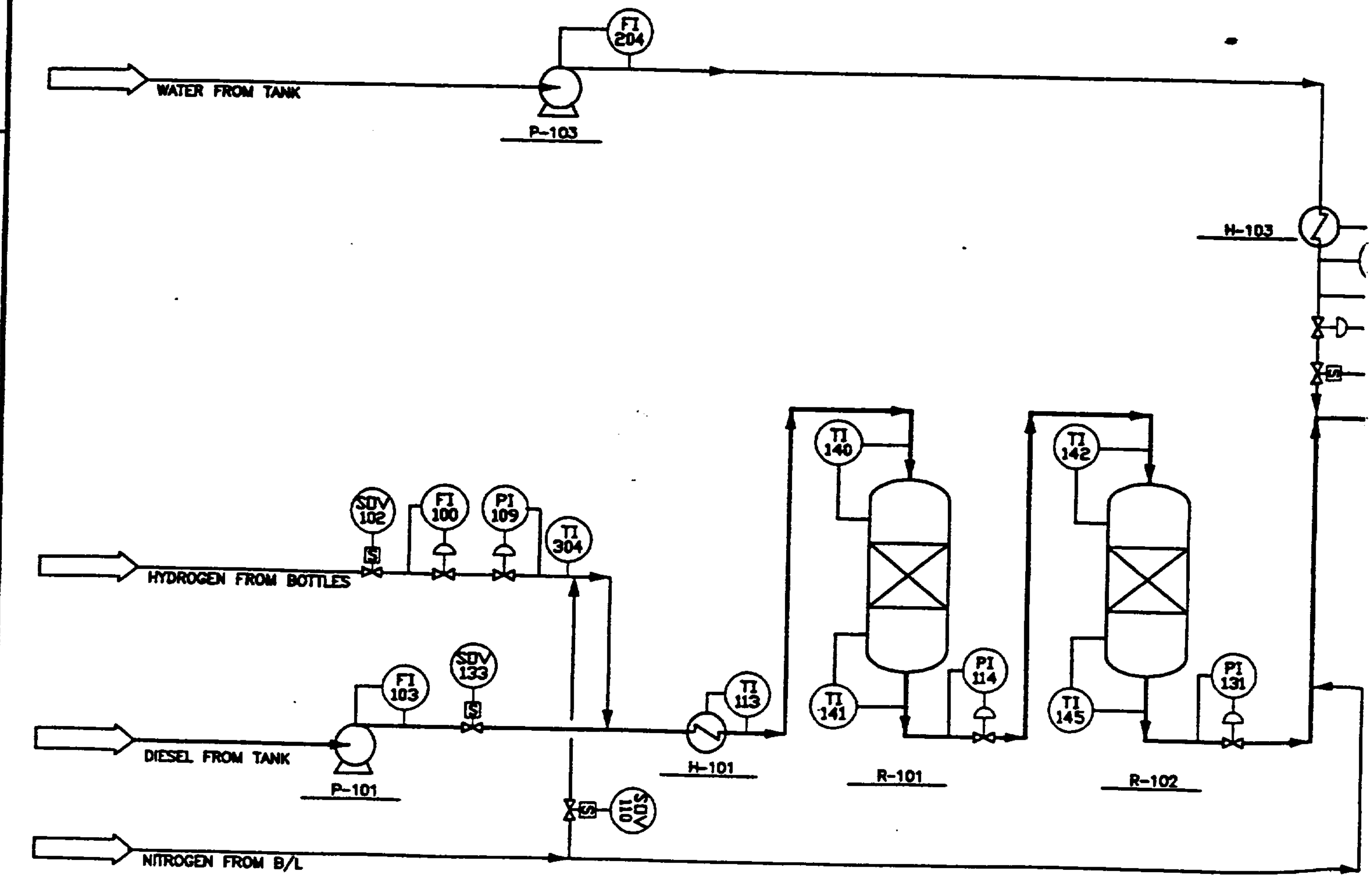
Diesel entering the skid is pumped to 50 bar abs in P-101. (65036-KD-011–Mechanical Flow Diagram). The speed of the pump is controlled by FI-103 which receives and ratios a signal from the fuel cell and a pressure signal from an indicator, PI-131, located in the line after the sulfur absorbers to determine the amount of diesel that needs to be pumped through the system. The signal from the fuel cell indicates the amount of processed gas the fuel cell is taking from the skid. The pressure signal indicates the pressure of the system after the sulfur absorbers. When the fuel cell first increases the amount of processed gas removed from the skid, the pressure in the system drops and more diesel is needed to return to normal operating pressure. Combined in ratio form, these signals allow the pump speed to be adjusted to send the correct amount of diesel through the system.

The flow transmitter, FI-103, measures the mass flow rate of the diesel, normally or maximum 6.2 kg/hr. This flow rate is used to control the flow rate of the hydrogen flow into the skid through the flow valve FI-100. Based on diesel (kg)/hydrogen (kg) ratio of 22.4/1 units, the flow rate of the hydrogen should be 3.1 Nm^3/hr at normal or maximum operating conditions. If the flow rate of the hydrogen is too low, the low flow alarm, FAL-100, will activate. Also, if the ratio between the diesel and hydrogen becomes too low, a low ratio alarm will activate causing a shutdown.

A pressure transmitter is located on the hydrogen line after the mass flow meter and pressure indicator, PI-109, is equipped with high pressure, low pressure, and low-low pressure alarms. If the low-low pressure alarm activates, it will cause the system to shutdown. A temperature indicator TI-304 will indicate the temperature of the incoming hydrogen. Normal operating conditions are 45 bar abs and 40°C.

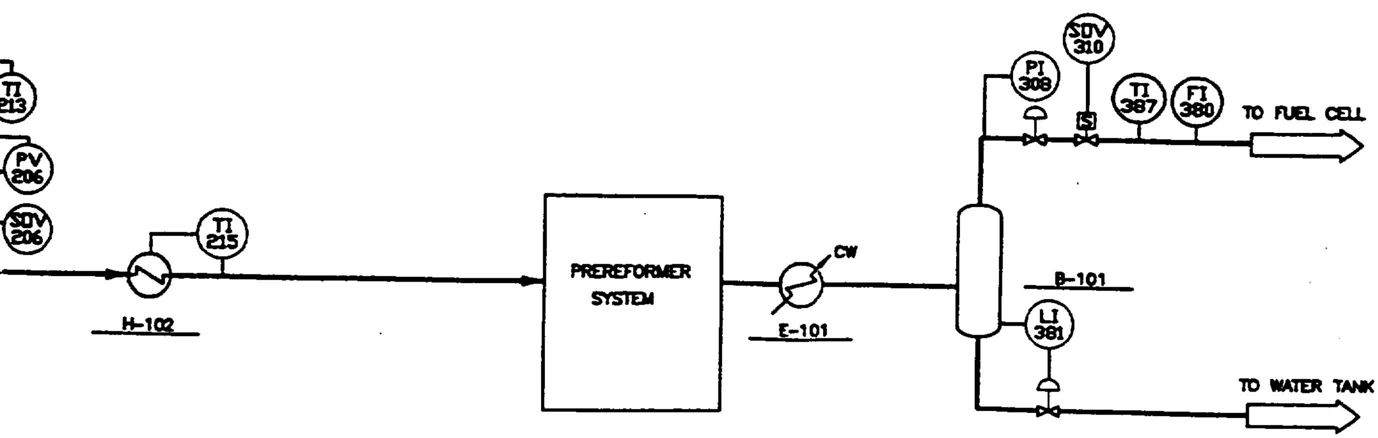
In case of a shutdown, solenoid valves SDV-133 and SDV-102 will close the diesel and hydrogen lines respectively.

STREAM NO.		1		2		3		4		5		6		
DESCRIPTION														
COMPONENT	MOL WT	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR
TOTAL (DRY)			100.00				100.00		100.00		100.00		100.00	
WATER K MOL/HR.														
TOTAL K MOL/HR (WET)														
TOTAL KG/HR.														
AVG. MOL. WT.														
PRESSURE, BAR ABS														
TEMPERATURE, DEG. C														



LEGEND		REV	DATE
	STREAM NUMBER		
	PRESSURE, BAR ABS		
	TEMPERATURE, °C		
	DUTY, KW		
	FLOW, KG/HR.		
	FLOW, M^3/h		
	POWER, KW		

MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %	K MOL/HR	MOL %
100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00



DESCRIPTION	DRAWN	CHECKED	DRAWN BY	AGP	9/29/97	CONFIDENTIAL
			CHECKED			
			PROCESS APPROVED			
			PROCESS MGR APPROVED			
			PROJ MGR APPROVED			
			CLIENT APPROVED			

HALDOR TOPSOE, INC.
HOUSTON, TEXAS

WESTINGHOUSE ELECTRIC CORP.
32KW SOFC BRASS BOARD

145364

PROCESS FLOW DIAGRAM

SCALE: NONE | DRAWING NUMBER: 65036-KD-006 | REV. 1

A B C D E F G

6 7 8 9 10

H-101

The diesel/hydrogen mixture is heated to 370°C in H-101, the HDS preheater. TI-113, which measures the temperature of the hot mixture, sends a signal to increase or decrease the heat to H-101 to maintain the outlet temperature at 370°C. The temperature indicator is equipped with high temperature, low temperature, and low-low temperature alarms. If the low-low temperature alarm activates, it will cause the system to shutdown. Also, a temperature element is located on the sheath of the heater, and if the sheath temperature becomes too hot, the temperature controller, will turn off the heater until it reaches a safe operating temperature.

A pressure relief valve, PSV-127, set at 60 barg, is located on the emergency vent line prior to H-101. Should the pressure of the gas entering H-101 raise above 60 barg, the valve will open and allow the gas to vent.

R-101

The pressure of the hot diesel/hydrogen mixture should be 44.8 bar abs when entering R-101, the HDS reactor. PI-114 measures the pressure of the fluid from R-101 and pressure indicator can adjust the pressure via a pressure control valve located on the outlet stream of R-101. The pressure indicator is equipped with high pressure, low pressure, and low-low pressure alarms. If the low-low pressure alarm activates, it will cause the system to shutdown.

To insure that the fluid is the correct temperature when it enters the catalyst bed a preheater is provided on the inlet to R-101. A temperature element, TI-140, measures the temperature out of the preheater and temperature indicator, TI-140 can adjust the heat to the coil accordingly.

Four adiabatic heaters are provided on R-101 to maintain the temperature in the reactor. In general the adiabatic heaters work using temperature elements located on the inner and outer edges of the layer of insulation closest to the reactor. These temperatures are compared and heat is added to the reactor if the temperatures are not the same. A temperature element measures the sheath temperature of the adiabatic heaters and should they become too hot, a temperature control will turn off the heaters until they cool to a safe operating temperature. On R-101, the four adiabatic heaters are evenly spaced on the outside of the reactor for between the top and bottom of the catalyst bed.

To maintain the gas temperature to the next reactor a post-heater is provided. It operates in the same manner as the preheater.

A sample point is located on the outlet of R-101.

<u>R-102A/B</u>
The sulfur absorbers, R-102A/B, are configured in the same manner as R-101 with pre and post heaters and four adiabatic heaters.

A sample point is located on the outlet of R-102A/B. A pressure transmitter, PI-131, measures the outlet pressure of the desulfurized gas. The pressure controller uses R-102 outlet pressure and to adjust the pressure control valve to the correct setting. The correct setting will both maintain adequate pressure upstream of R-102A/B and allow enough gas to pass to R-103 and on to the fuel cell. PI-131 also sends a signal to the diesel inlet flow controller, FI-103, to maintain the correct diesel flow into the skid.

In case of shutdown, the solenoid valve SOV-207 on the desulfurized gas line closes and the solenoid valve SOV-208 on the emergency vent line opens, allowing the gas to escape via the emergency vent line.

Prereforming

<u>P-103</u>
The flow transmitter FT-228 measures the mass flow rate of the desulfurized gas, normally 142 SCFH. This flow rate is used to control the flow rate of the water into the skid. Based on gas (kg)/water (kg) ratio of 1/5.6 units, the flow rate of the water should be 36.6 kg/hr at normal operating conditions. The flow rate of the water is controlled using the BFW pump, P-103. The mass flow meter, FI-204, measures the inlet flow of the water.

FI-204 then sends the appropriate signal to P-103 to pump more or less water as necessary. The flow controller is equipped with high flow, low flow, and low-low flow alarms. If the low-low flow alarm activates, it will cause the system to shutdown. Also, if the ratio between the gas and water becomes too low, a low ratio alarm will activate causing a shutdown.

<u>H-103</u>
The pressurized water is evaporated in H-103, the steam evaporator. The steam should be at 24.5 bar abs and 320°C. TI-213 measures the temperature of the vapor and sends a signal to H-103 to increase or decrease the heat to maintain the outlet temperature at 320°C. The temperature indicator is equipped with high temperature, low temperature,

and low-low temperature alarms. If the low-low temperature alarm activates, it will cause the system to shutdown. Also, a temperature element is located on the sheath of the heater, and if the sheath temperature becomes too hot, the temperature control will turn off the heaters until they reach a safe operating temperature.

A pressure relief valve, PSV-209, set at 30 barg, is located on the emergency vent line directly after H-103. If the pressure is higher than 30 barg the valve will open and allow excess gas to vent.

In case of shutdown, the solenoid valve SOV-206 on the steam line closes and the solenoid valve SOV-226 on the emergency vent line opens, allowing the steam to escape via the emergency vent line.

A pressure transmitter, PI-206, measures the gas pressure after H-103 and can adjust the pressure using the pressure control valve.

<u>H-102</u>

The desulfurized diesel/hydrogen mixture and the steam from H-103A/B/C/D/E, mix just prior to entering H-102.

The gas/steam mixture is heated to 480°C in H-102, the prereformer preheater. TI-215 measures the temperature of the gas out of H-102 sends a signal H-102 to increase or decrease the heat to H-102 to maintain the outlet temperature at 480°C. The temperature indicator is equipped with high-high temperature, high temperature, low temperature, and low-low temperature alarms. If either the high-high temperature or low-low temperature alarm activates, it will cause the system to shutdown. Also, a temperature element is located on the sheath of the heater, and if the sheath temperature becomes too hot, the temperature control will turn off the heater until it reaches a safe operating temperature. In case of a shutdown, TI-215 will stop all heat to H-102.

A pressure relief valve, PSV-216, set at 30 barg, is located on the emergency vent line directly after H-102. If the pressure is higher than 30 barg the valve will open and allow excess gas to vent.

<u>R-103</u>

Pressure transmitters, monitor the inlet and outlet pressures to R-103, and calculate the pressure drop across the vessel.

R-103 is similar to R-101 and R-102A/B because it too has a vessel preheater and external adiabatic heaters.

Also, twelve temperature indicators are arranged throughout the catalyst bed to monitor catalyst activity.

A temperature element monitors the temperature of the prereformed gas out of R-103.

<u>E-101</u>

E-101, the product cooler, cools the prereformed gas to 40°C using air as the cooling medium.

<u>B-101</u>

The water is removed from the product gas in, B-101, the product gas separator. The level is controlled in the separator using a level transmitter and a level control valve on the liquid outlet of the tank. The level transmitter, LI-381, reads the level in the tank and the level indicator sends the appropriate signal to the level control valve to open or close as necessary to maintain an even liquid level in B-101. High level and low level alarms are provided on the level indicator. The water from B-101, usually 16 kg/hr, returns to a water tank off of the skid.

TI-387, a temperature indicator, reads the temperature of the product gas from B-101. A pressure transmitter, PI-308, monitors the pressure of the B-101 product gas and pressure indicator opens a pressure control valve on a line to the emergency vent should the pressure become too high. Normal operating temperature and pressure for the line are 40°C and 20.8 bar abs.

When the pressure drops at the outlet of R-103 the pressure transmitter on the outlet of R-103 will also measure a low pressure. This pressure transmitter sends a signal to a pressure controller on R-102 outlet. The pressure controller uses the R-102 outlet pressure and R-103 outlet pressure to adjust the pressure control valve exit R-102.

A mass flow meter, FI-380, measures the flow rate of the product gas, usually 11 Nm^3/h.

In the event of a shutdown a solenoid valve at the end of the product gas line will close. Therefore, no gas will be available for the fuel cell.

START-UP & SHUTDOWN

HDS Section

Before start-up of the skid, disable appropriate alarms. At the beginning of start-up, nitrogen should be flowing through the system. The set points of PI-114 and PI-131 should each be set at 10 bar. H-101 and the R-101 and R-102A/B preheaters, start-up heaters and post heaters should all be activated with a set point of 50-75°C above their current temperature. Raise the set points in 50-75°C increments to reach a final set point of 400°C. When all heaters have steady output values, the nitrogen flow to the system is stopped by closing the solenoid valve SOV-110. The hydrogen flow to the skid is initiated by opening the solenoid valve SOV-102 and setting the flow control valve set point. Next the diesel solenoid valve SOV-133 should opened and the diesel pump, P-101, turned on. Slowly raise the set point of PI-114 in small increments to the normal set point of 45 bar.

When the diesel flow rate, diesel/hydrogen ratio, and H-101 outputs are all reporting steady readings, H-101 and the R-101 and R-102A/B preheaters, start-up heaters and post heaters' set points should be changed to 380°C. Alarms can now be activated. Next, slowly raise the set point of PI-131 in small increments to the normal operating pressure of 25 bar. These conditions should be maintained until merging the HDS and prereformer sections of the skid.

Pre-reformer Section

Before starting up the prereformer section of the skid, disable the appropriate alarms and reset any trip buttons, as necessary. Start by raising the set point of PI-308 to 10 bar. When a pressure of 10 bar is reached closed the solenoid valve SOV-210 to stop the flow of nitrogen to the skid. Next, the R-103 preheater and post heater should be activated with a set point of 50-75°C above their current temperature. Raise the set points in 50-75°C increments to reach a final set point of 500°C. Also, turn on the, R-103, adiabatic heaters when the, R-103, heaters are activated. Next, turn on P-103 with a set point of 20 kg/hr. Once the flow is steady H-103 can be activated with 50% power. In the HDS Section, adjust the diesel flow so that the diesel/hydrogen ratio is reduced to 10.

When the diesel/hydrogen ratio, the heater outputs, the steam flow, and the bed temperatures in R-103 are all steady, close the steam vent. When the steam pressure at PI-206 reaches 27 bar, put the steam system in automatic control. Now, the desulfurized steam/hydrogen mixture can be introduced to H-102. When flow is introduced the prereformer section, the output temperature of H-102 should stay near 450 °C, and the prereformer bed temperatures should stay above 450 °C during start-up.

When H-102 is steady, raise the diesel/hydrogen ratio to 20. Also, turn off the start-up heaters, lower the steam temperature to 330 °C, and activate alarms. Once the system seems steady, begin to increase flows in small increments until desired capacity is reached. At this point, fuel can be sent to fuel cell.

Shutdown System

A shutdown of the Fuel Skid can be accomplished manually by pushing an emergency shutdown button located at the fuel skid or by pushing the emergency shutdown button on the operator interface screen.

The trip system is divided into two sections. The first section of the trip system monitors the HDS section of the skid. A trip of this system will result in the shutdown of the entire skid. An emergency stop button will initiate a first section shutdown, as well as too low or high flow or pressure of either the fuel or hydrogen. Any problems with the flare can also cause a shutdown. When this system trips, the prereformer will trip, all heaters will shutdown, and the fuel and hydrogen flows will stop. Nitrogen flow will start to purge the system.

The second section of the trip system monitors the prereformer section of the skid. If a problem with the HDS section does not initiate the trip of this system, only the prereformer section of the skid will shutdown, while the HDS section will continue to operate sending the fuel to the flare system. Too low or high steam pressure, temperature, or flow, as well as, too low or high temperatures in the prereformer can cause a shutdown. When the system trips, the steam vent will open, and the steam system will shutdown. A solenoid valve will close diverting fuel flow from the fuel cell to the flare. All heaters will turn off, and nitrogen purge will be introduced.

OPERATING SUMMARY

Introduction

The following chronological sequence details the most important aspects of commissioning, start-up, and operation of the Logistic Fuel Processor (LFP). All operations occurred at the Southern California Edison (SCE) National Fuel Cell Test Center, located at the Highgrove Generation Station, Grand Terrace, California. SCE also provided the operating personnel. Commissioning and start-up was accomplished via a comprehensive team effort, with personnel from SCE, HTI, and Texas Systems and Controls, Inc. (the skid fabricator) contributing heavily.

Operational Summary

Date	Action
June 6, 1995	Skid arrives in California. Installation begins with piping hook-up, instrumentation check-out, control system hook-up, flare installation, and organization of feedstock and utilities.
July, 1995	Begin initial system start-up activities; start-up HDS section, and produce steam for prereforming section.
July 22, 1995	Catastrophic failure (internal leak) of steam generator heater. Failure requires replacement of one heater, and repair of remaining four heater elements.
August 15, 1995	Restart of LFP and stabilization of operation.
August 24, 1995	Begin delivery of jet fuel reformate to SOFC. Unit runs well. Reformate is on specification. Capacity is limited because heaters cannot reach design temperature at full flow rates.
Sept. 18, 1995	LFP is shut down after 575 hours of delivering fuel to SOFC, (95.8% on-line). LFP will be modified to add additional heater capacity.
October 3, 1995	After addition of heaters, unit is restarted and began delivering reformate to SOFC.

October 11, 1995	Supply of jet fuel is nearly exhausted and diesel (DF-2) is added to fuel supply tank. LFP will run continuously during transition. LFP test period on diesel begins in afternoon. Delivered jet fuel reformate to SOFC for a total of 766 hours.
October, 1995	LFP processing DF-2. From October 11 to October 31, LFP was down for one week due to heater failure. Restarted LFP with a bad heater, to see if unit could run. Operations acceptable with bad heater. 106 hours diesel reformate delivered to SOFC during October.
November, 1995	LFP tripped off line due to bad motor on cooling fan. When repaired, LFP would not start due to failed heater. Unit shut down to repair heater. LFP re-started on November 30. LFP accumulated no run hours during November.
December, 1995	LFP operated until December 7, when a vibration on skid caused PLC outage. Unit re-started on December 11th. After shutdown, noticed deactivation of prereforming catalyst. On December 12, reformate was again delivered to SOFC. Unit continued operation for remainder of December. Diesel reformate delivered to SOFC (cumulative) for 692 hours.
January, 1996	LFP operated in January with only two shutdowns, one due to a high separator level and the other due to a loss of steam pressure. On January 5, thiophene was added to the diesel feed, increasing inlet sulfur concentration to 2300 ppm (wt). Diesel reformate delivered to SOFC (cumulative) for 1300 hours.
February, 1996	On February 2nd, LFP shutdown on H-101 heater failure. Heater was repaired and LFP brought back on-line on February 8th. Additional thiophene was added to raw diesel on February 2nd, increasing sulfur level to 3090 ppm (wt). Unit operated until February 16th, when it was manually shut down, having processed and delivered diesel reformate to the SOFC for 1554 hours.

ANALYSIS OF OPERATION - CATALYSTS

Hydrodesulfurization

The purpose of the hydrodesulfurization section of the LFP was to convert all sulfur compounds into H2S. The H2S would then be adsorbed by the zinc oxide beds so that a sulfur-free hydrocarbon stream would be sent to the prereformer. Samples of the hydrocarbon stream were analyzed for sulfur, with acceptable results. Please refer to the section **"Sulfur Results"** for further details.

Adiabatic Prereforming

The deactivation of the catalyst in the prereformer (R-103) can occur during three fundamental situations: deactivation, carbon formation and oxidation. Of primary interest in the catalyst is sulfur, present in the prereformer feed because it was not completely removed in the hydrosulfurization (HDS) step. Carbon formation is a function of the temperature in the catalyst bed. Too low of a temperature will form gum on the catalyst, and too high of a temperature will cause cracking and the formation of whisker carbon on the catalyst. The third primary cause of deactivation is the oxidation of the nickel contained in the catalyst. All of these situations will cause the catalyst to lose activity. This loss of activity, or deactivation, of the prereforming catalyst can be seen in catalyst temperature profile of the prereformer reactor. As the upper portions of the catalyst bed lose activity, no reactions take place in this area, and the temperature will remain constant. As the higher hydrocarbons reach a point in the bed where the catalyst is active, adiabatic prereforming begins and a temperature rise is seen. The temperature continues to increase until equilibrium is reached and the temperature once again stabilizes at a higher level. (Graphical representations of the LFP prereformer's temperature profile over time are enclosed at the end of this section.)

Sulfur Results

Throughout the course of the operation of the LFP, samples of diesel were taken and analyzed for sulfur. The results of this analysis are shown in Table 1 at the end of this section. This table show that throughout the operation of the LFP, sulfur levels existing in the one-stage HDS section and entering the prereformer were less than 1 ppm (wt). This was one of the goals of the brassboard test program, and minimized the deactivation of the prereformer catalyst due to sulfur poisoning.

During the last 550 hours of operation, some deactivation of the prereformer catalyst was seen. This is evidenced by the movement of the temperature profile. As seen no progressive movement of the profile is seen for the first 2300 hours of operation. The last 550 hours of prereformer run time correspond to the addition of thiophene to the diesel feed. No explanation is available as to why the HDS section did not completely remove the sulfur after thiophene was added.

Carbon Formation

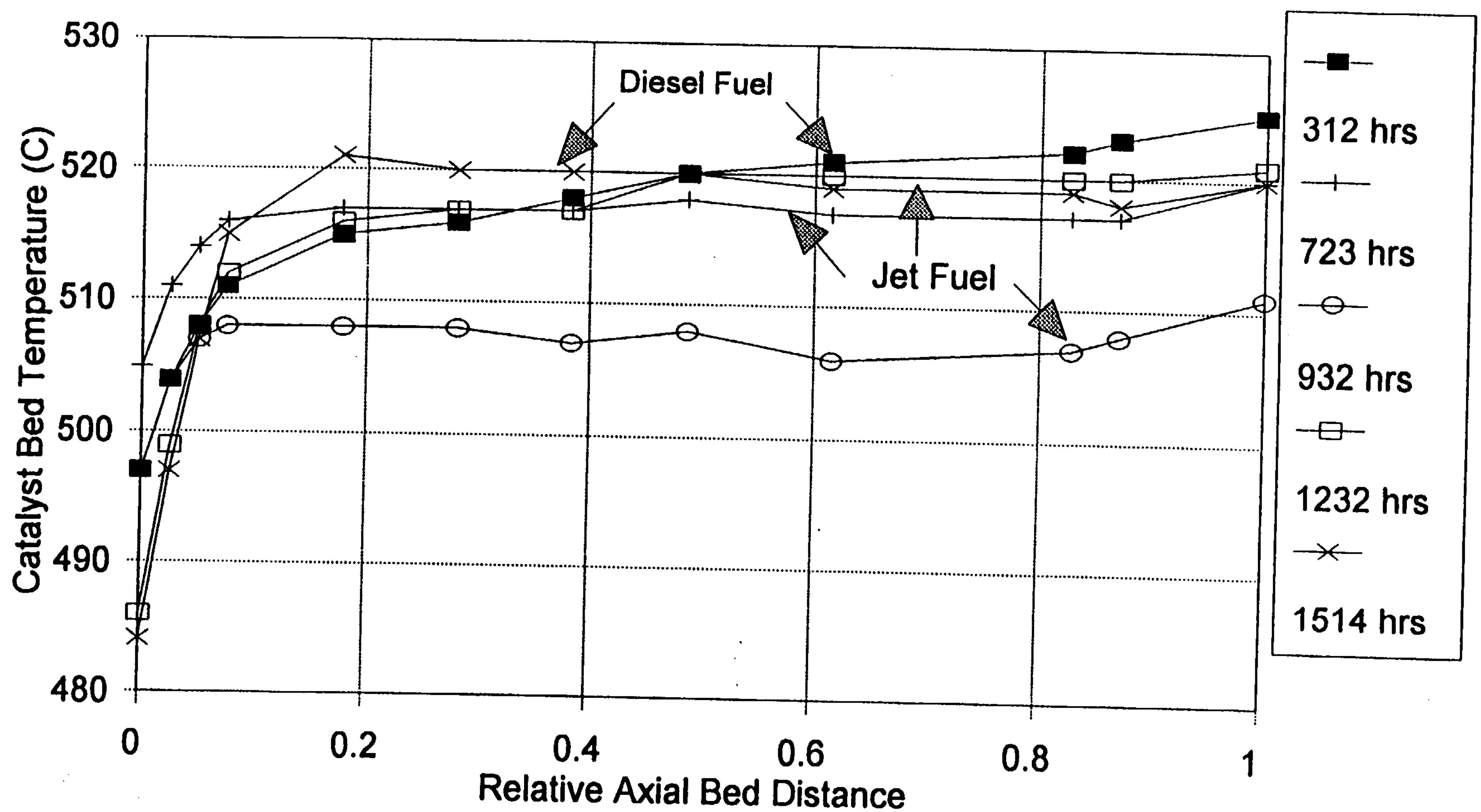
Carbon formation is most easily recognized by analysis of the used catalyst. Based on the catalyst analysis, little carbon was formed on the prereforming catalyst. (See Appendix 1 for additional details on this evaluation.)

Oxidation

The oxidation of the nickel within the catalyst is typically caused by the influx of steam without the presence of hydrocarbons. In the analysis of the catalyst, the upper portion of the catalyst bed was noted as containing excessive amounts of oxidized nickel. It is possible that during the PLC shutdown of December 7, 1995, steam, without diesel, was injected into the prereformer. Because it was a control system failure, no data are available on the cause or sequence of events following the shutdown. This tends to explain the significant deactivation of the top portion of catalyst at 1514 hours, as well as presence of oxidized nickel in the same area.

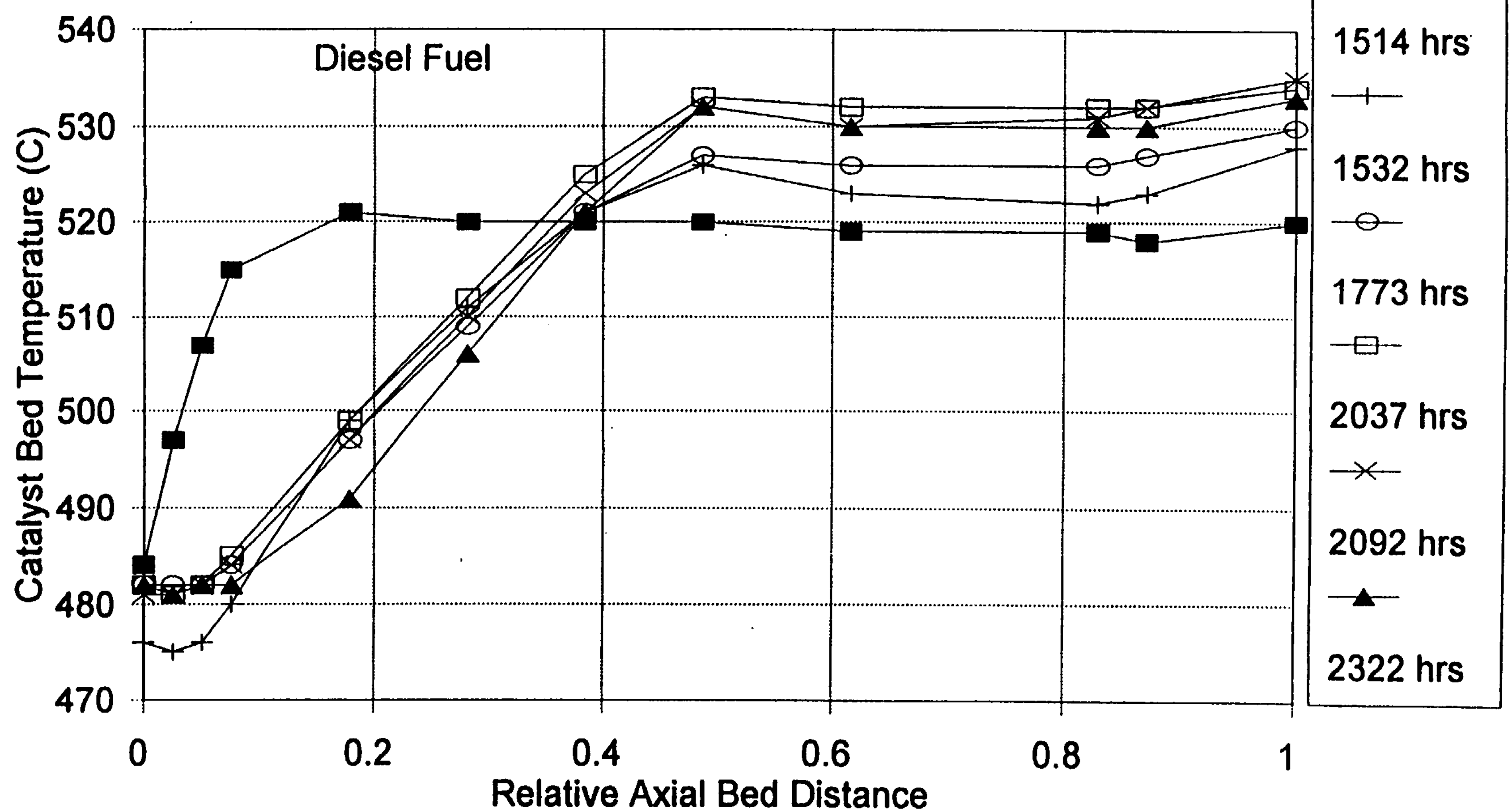
R-103 Temperature Profiles

Based on Total Hours of Runtime



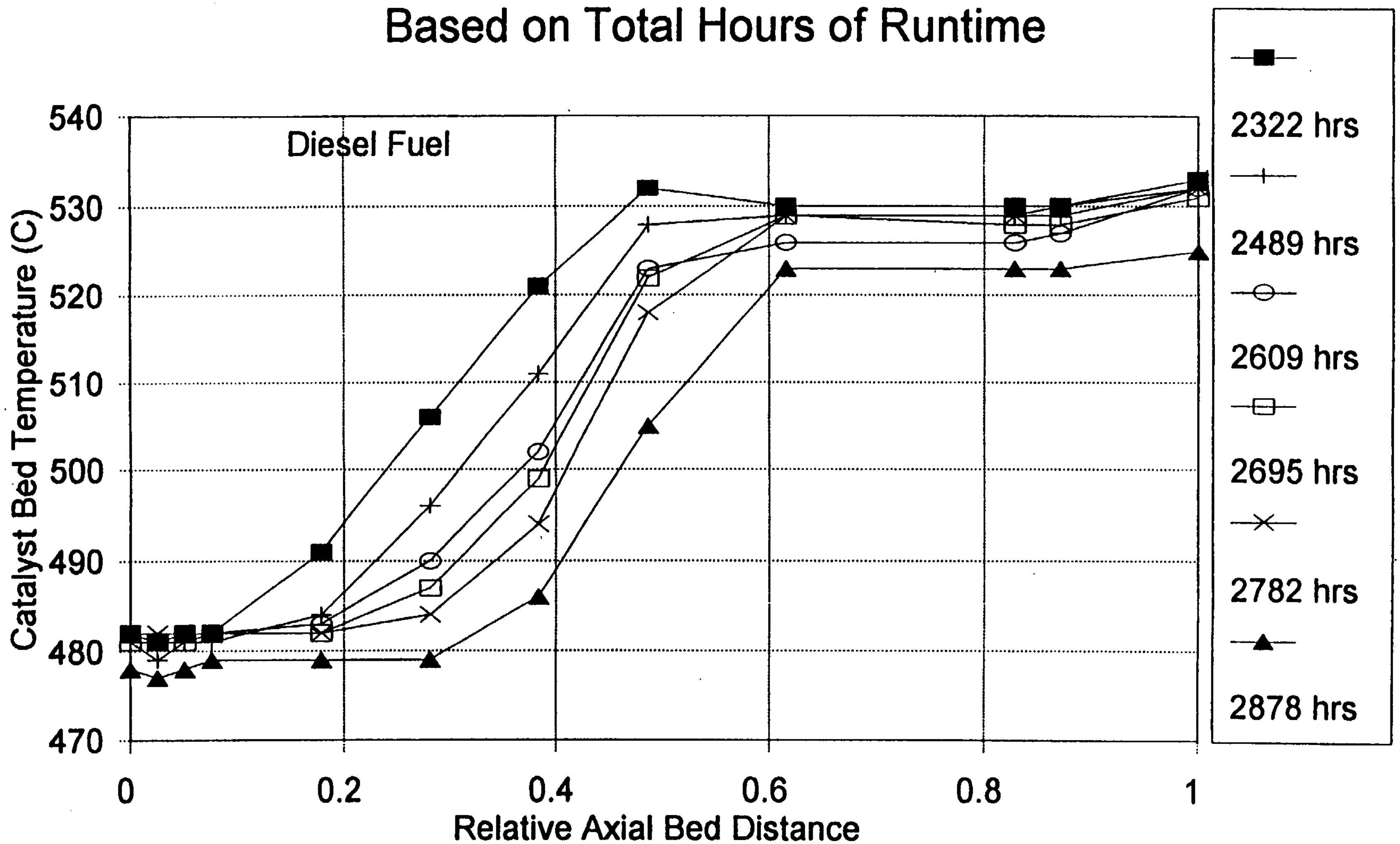
R-103 Temperature Profiles

Based on Total Hours of Runtime



R-103 Temperature Profiles

Based on Total Hours of Runtime



ANALYSIS OF OPERATION - EQUIPMENT

Rotating Equipment

The LFP also had two metering pumps, used to pump diesel and water into the system. These pumps also operated satisfactorily.

Heat Exchangers

The LFP contained no heat exchangers that were used for heat recovery. Two air cooled exchangers were utilized to cool the product gas after exiting the prereformer. No difficulties were encountered with these units.

Electric Heaters

The LFP contained several electric heaters. One was used to vaporize the incoming diesel to 380°C. Another set of electric heating elements, five (5) elements arranged in separate vessels in series, were utilized to generate superheated steam at 25 barg, and 480 °C, in a once through system. Two more electric heaters were utilized to heat the desulfurized diesel and hydrogen, to the operating temperature of the prereformer, 480°C, at inlet.

The heaters posed the most difficult operation. Several failures occurred, typically due to electric heater burnout. The steam generating heaters were very susceptible to water encroachment into the magnesium oxide layer covering the heating element. If heated with water in the magnesium oxide, the heater would fail. This did occur on more than one occasion. The hydrocarbon heaters were susceptible to coke build up on the heating elements due to cracking of the hydrocarbons. High temperature requirements and low flowrates combined to form an extremely severe service.

Most of the operational difficulties were due to electric heating element failures.

Control System

The control system utilized a programmable logic controller (PLC) on board the LFP skid. This PLC controlled the skid's process requirements and safety shutdown system. Operator interface to the PLC was provided via a personal computer and a commercial software package that would communicate with the PLC. The operation of this system was satisfactory.

One PLC shutdown did occur, when one of the control cards in the PLC apparently vibrated loose from the rack. This caused a shutdown, but the details are unavailable.

LESSONS LEARNED

From the operation of the brassboard LFP, several important facts were confirmed. Most importantly, it was learned that a fuel processor could be designed and operated to utilize jet fuel or diesel, and convert these military type fuels, into a fuel compatible with a SOFC. The process layout, using a one step deep desulfurization followed by adiabatic prereforming, provided an acceptable fuel for long-term operation of the SOFC.

Secondly, several design factors, including the operating temperatures, pressures, and space velocities for the reactors were confirmed. These values can be directly transferred and utilized in the design of mega-watt class fuel processors.

It was also learned that the SOFC operated on the reformate of jet fuel or diesel with no deleterious effects. The LFP and the SOFC were operated both separately (with the other unit down), and together, with the LFP providing fuel to the SOFC.

The results of this operation will be utilized in the design of the mega-watt class fuel processor.

<u>Attachment 1 to Appendix E</u> (pages E-28 through E-34)

Analysis of Spent Catalyst form Westinghouse/ARPA (HTAS telefax dated August 15, 1996).

Telefax

Dist: NRU JSL A6P MMP KEA

HALDOR TOPSØE A/S

Nymøllevej 55, DK-2800 Lyngby, Denmark - Telephone +45 45 27 20 00
Telefax +45 45 27 29 99/+45 45 87 64 94 (Group III - Xerox 7020)
Telefax operator direct telephone +45 45 27 22 75 - Telex 37 444 htas dk

Date : August 15, 1996

Message No.: 404

To:

Company : HTI
Location : El Camino Real
Attention : MMP cc: NRU, JSL
Telefax No. :
Your ref. : 65036

From:

Name : Thomas S. Christensen
Our Ref. : HTAS File 36565 - TSC/BR (please quote)
No. of pages: 5

cc: : JRN, JHBH, EJJ, KAA, BC, LS, TSC 9

Subject: Analyses of Spent Catalyst from Westinghouse/ARPA

The spent catalyst from the Fuel Processing System of Westinghouse/ARPA 32 kW Brass Board Plant has been analysed as requested by you. The report summarising the results is enclosed. If you have any questions or comments please do not hesitate to contact me.

Kind regards,

Thomas S. Christensen

Thomas S. Christensen

HALDOR TOPSØE A/S
DK-2800 LYNGBY
DENMARK

Lyngby, August 13, 1996
TSC/BR

File 36565

Analyses of Spent Catalyst from Westinghouse/ARPA Brass Board Plant Collected April 1996

1. Introduction

Catalysts from the Fuel Processing System of the Westinghouse 32 kW SOFC Brass Board Plant were unloaded in April 1996 after a total of 2,700 hours of operation (766 hours on jet-fuel and 1,918 hours on diesel). This report summarises the catalyst analyses performed on the samples of TK-525, HTZ-3 and RKNGR catalyst.

2. Results of Catalyst Investigations

The results are listed in Tables 1 to 3.

2.1 Hydrogenation Catalyst, TK-525

2.1.1 Sulphur

The catalyst samples are in a fully sulphided state as intended.

2.1.2 Carbon

The carbon content of the top samples of TK-525 is normal and in the same range as found after the HTAS pilot plant demonstration tests. The carbon content of the lower samples is relatively high and could indicate some degree of catalyst deactivation.

Table 1 Analyses of spent TK-525 catalyst

[illegible]	[illegible]	[illegible]	[illegible]
R-101 - 1	Top	9.4	8.2
R-101 - 3	0.30 m	14.5	8.0
R-101 - 6	0.76 m	18.4	7.7

2.1.3 ZnO Sulphur Absorption Mass, HTZ-3

2.1.4 Sulphur

The sulphur content of the top sample is 20 wt.%, which is approx. 2/3 of the maximum absorption capacity. The sulphur level of the following samples is in the range 8-12 wt.% and the sulphur absorption front has reached approx. 75% down in the first ZnO reactor. This shows that the first ZnO bed still has sufficient capacity for the bulk absorption of sulphur. No sulphur is found in the second reactor, so this reactor is also available for sulphur absorption.

The sulphur profile through the first reactor looks strange, which could indicate that some of the samples have been mixed-up and labelled erroneously. The figures for samples 3 and 6 do not fit into the expected profile.

2.1.5 Carbon

The carbon content of the ZnO samples is within the normal range. Sample 3 from the first reactor has a deviating number, which is difficult to explain.

Table 2 Analyses of spent HTZ-3

[illegible]	[illegible]	[illegible]	[illegible]
R-102A - 1	Top	0.44	19.9
R-102A - 3	0.30 m	0.03	0.6
R-102A - 5	0.61 m	0.73	7.6
R-102A - 6	0.76 m	0.71	1.6
R-102A - 7	0.91 m	0.65	11.4
R-102A - 9	1.22 m	0.64	9.9
R-102A - 11	1.52 m	0.65	<0.02
R-102B - 1	Top	0.49	<0.2
R-102B - 7	0.94 m	0.94	<0.02

2.2 Adiabatic Prereforming Catalyst, RKNGR

2.2.1 *Visual Inspection*

A visual inspection of the catalyst shows that the catalyst pellets are generally in good condition.

2.2.2 *Reduced Nickel*

The content of reduced nickel is 9-11%, which is less than half the expected value (25 wt.%). The catalyst has thus been oxidised at some stage of its life, presumably by steaming. At normal operating conditions and when operating procedures are followed, the RKNGR catalyst will remain fully reduced as delivered. However, the normal operating conditions are not able to re-reduce the catalyst when it has become oxidised. A considerable reduction of the activity for this RKNGR catalyst bed is expected, as the activity is proportional to the contents of reduced nickel.

2.2.3 *Sulphur Poisoning*

The sulphur adsorption profile is quite unusual with a relatively low sulphur coverage in the top and increasing sulphur coverage down to a peak in the middle of the bed where the catalyst is almost fully covered by sulphur. The shape of the profile indicates that some sulphur has been removed from the top part of the catalyst, most likely in connection with an oxidation of the catalyst by steaming. By integration of the amount of sulphur on the catalyst it has been found that 18 g sulphur has been adsorbed on the catalyst. Whether some sulphur has been removed from the catalyst and transported to downstream units is uncertain. The amount of adsorbed sulphur on the catalyst corresponds to a continuous addition of 1.4 ppm (w/w) sulphur during the 2,684 hours the prereformer was in operation on JP-8 and DF-2 (2.1 ppm if only the DF-2 period is considered).

2.2.4 *Carbon Formation*

The catalyst that is partly sulphur deactivated contains 2-7% carbon. This level is within the normal range for a sulphur deactivated catalyst. The amount of carbon is lower than found on the HTAS pilot plant tests when the operation time is taken into account.

The top sample has also been investigated by electron microscopy and no carbon whiskers have been found on this sample, which shows that the operation has not exceeded the carbon limit.

2.2.5 *Other Poisons*

The top samples have been analysed for some other potential poisons; Si, K and Na. The analyses show low values indicating that no poisoning by such elements has taken place.

Table 3 Analyses of spent RKNGR catalyst

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
R-103 - 1	Top	7.1	0.23	9.3
R-103 - 2	0.10 m	6.6	0.21	
R-103 - 4	0.30 m	7.0	0.44	
R-103 - 6	0.50 m	6.0	0.65	
R-103 - 8	0.71 m	5.6	0.63	
R-103 - 10	0.91 m	2.5	0.80	
R-103 - 12	1.22 m	0.44	0.07	
R-103 - 16	1.78 m	0.30	0.03	11.6

3. Conclusion

In general, the catalyst appears to be in a satisfactory condition, which can also be seen by the highly satisfactory operation of the Westinghouse fuel processing system on both JP-8 and DF-2 feeds.

The zinc-oxide beds with HTZ-3 have abundant capacity for sulphur absorption; the profile has reached 75% down in the first reactor and no sulphur has reached the second reactor.

No carbon whiskers are found on the RKNGR catalyst showing that the applied operating conditions have been within the acceptable limits for carbon formation. The sulphur content of the RKNGR catalyst is within the expected range, but the profile is quite unusual most likely due to the fact that the catalyst by some incident has been oxidised, for example by steaming. The conclusion drawn on the basis of the catalyst analyses is that the RKNGR catalyst is heavily deactivated in the upper 50% of the bed due to the combined oxidation and sulphur poisoning.

Thomas S. Christensen

SULFUR SAMPLE LOG & ANALYSIS RESULTS - Table 1

SAMPLE DATE	DETECTABLE LIMIT (PPM)	RESULTS	UNITS	LABS	NOTES
JET					
07/24/95	1	ND		Del Mar	
08/21/95	1	ND		Del Mar	
08/28/95	1	ND		Del Mar	
09/05/95	1	ND		Del Mar	
09/11/95	1	ND		Del Mar	
09/18/95	1	ND		Del Mar	
09/28/95	1	ND		Del Mar	
10/04/95	1	ND		Del Mar	
DIESEL					
10/11/95	1	277	ppm	Del Mar	Raw Diesel, From Tank (.028 wt%)
10/12/95	1	14	ppm	Del Mar	From HDS, Suspect Contaminated Sample
10/16/95	1	ND		Del Mar	From HDS, R101 @ 45 bar
10/16/95	1	ND		Del Mar	From HDS, R101 @ 50 bar
10/26/95	1	ND		Del Mar	From HDS, R101 @ 385 Deg C
10/30/95	1	ND		Del Mar	From HDS
11/06/95	1	1	ppm	Del Mar	From HDS
12/04/95	± 150 ppb	500	ppm	ERC	From HDS
12/12/95	± 150 ppb	0.5	ppb	ERC	From HDS
12/18/95	± 150 ppb	No Results		ERC	From HDS
01/02/96	± 150 ppb	No Results		ERC	From HDS
01/04/96	± 150 ppb	No Results		ERC	From Tank, Prior to Thiophene Addition
01/04/96	± 150 ppb	No Results		ERC	From HDS, Prior to Thiophene Addition
01/05/96					Added Thiophene
01/11/96	± 150 ppb	No Results		ERC	From Tank, After Thiophene Addition
01/11/96	± 150 ppb	1.32	ppm	ERC	From HDS, After Thiophene Addition
01/18/96	± 150 ppb	245	ppb	ERC	From HDS
01/23/96	1	2	ppm	Del Mar	From HDS
01/25/96	1	2311	ppm	Del Mar	Raw Diesel From Tank, Adulterated
02/02/96	0.01	0.309	wt%	Del Mar	Raw Diesel From Tank, Adulterated
02/09/96	1	5	ppm	Del Mar	From HDS

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APPENDIX F

Logistics Fuel Process Demonstration
Edison Site

Operator's Report

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Logistics Fuel Process Demonstration
Edison Site Summary

Project Objective

The program objective was to demonstrate operation of a Westinghouse 27 kW Solid Oxide Fuel Cell (SOFC) on logistic fuels, mil spec aviation jet fuel (JP-8) and diesel (DF-2). The established acceptance criteria were to operate for 500 hours on jet fuel and 1500 hours on diesel. The power output of the SOFC during the endurance portion of the test was not formally established, but at some point in the demonstration, SOFC peak power was to be achieved.

Project Participants

In order to use logistics fuels, the SOFC required that the jet and diesel be reformed into simpler gaseous hydrocarbons. This was achieved by a Haldor Topsoe Inc. (HTI) designed Logistics Fuel Processing (LFP) skid. The skid was constructed by Texas Systems and Controls, Inc (TSCI). The test site was the Southern California Edison (Edison) Highgrove Generating Station which was the location of an operating SOFC for the year prior to the logistics fuel demonstration. The stack of this machine was replaced in May 1995, prior to the test. Edison provided operations and maintenance personnel to conduct the test.

Project Schedule

The test was originally scheduled to occur between June 1995 through December 1995, but LFP skid reformer operation wasn't started until August 1995, and the demonstration was not completed until mid February 1996.

Logistics Fuel Processing (LFP) Skid

The LFP skid was designed for use by two fuel cell technologies, the SOFC at Edison's site in California and a Molten Carbonate Fuel Cell (MCFC) located at a site in Connecticut. The LFP skid was specified to provide sufficient fuel to achieve a peak power of 32 kW and operate for 500 hours on jet fuel and 1500 hours on diesel fuel. The skid was designed to be capable of providing 20 bar (approximately 300 psig) of logistics fuel reformate which consisted of methane (50%), hydrogen (30%) and the remainder carbon dioxide (20%) for both the jet and diesel fuels. The CO_2 is a byproduct of reformation and is not useful to the fuel cell. The SOFC was limited to receiving gas at less than 100 psig, so a pressure control valve at the LFP skid limited skid output to 6.9 bar, and an additional pressure relief was installed in the reformate line at the Edison site.

In addition to a peak fuel flow rate of 6.2 kg/hr, the LFP skid reformation process required pure water at a peak flow rate of 32 kg/hr, and hydrogen at a peak flow rate of 0.24 kg/hr. These flow rates were proportionally reduced for power outputs less than 32 kW. Since the peak power of the SOFC is 27 kW, the peak LFP process flow rates were never required. Though not demonstrated during this project, a part of the hydrogen from the reformate stream could be recycled to the input of the process which would greatly reduce the hydrogen supply requirements for the LFP skid.

The Edison site was tasked with providing auxiliary support systems including all electric power, and hydrogen, water, fuel, and nitrogen (used to purge skid systems following shutdowns) requirements for the LFP skid.

SOFC Operations

During periods when the LFP skid was not operational, the SOFC operated on natural gas. The SOFC shifted to natural gas operation automatically upon failure of the LFP skid, except on two occasions when the SOFC failed to make such a transition (12/7/95 & 2/2/96). It is believed that a software modification corrected this problem, but this was not demonstrated since no LFP skid trips occurred after the software change. Incidentally, because the site's natural gas pressure is limited to 40 psig, the peak power of the SOFC cannot be achieved on natural gas at Edison's site. Consequently, during most of the LFP demonstration, SOFC power output was limited to about 22 kW, a power which can be comfortably sustained with the site's natural gas supply in the event of an LFP trip.

Project Results

The SOFC achieved a peak output on both logistics fuels. During the jet fuel reformate demonstration, SOFC power was increased to 27 kW (internal) on 10/4/95. During the diesel reformate demonstration, the SOFC power was increased to 27 kW (internal) on 1/4/96.

At the conclusion of the test at the Edison site, the SOFC operated on jet fuel for 766 hours, the LFP skid operated on jet fuel for 964 hours. The SOFC operated on diesel fuel for 1555 hours, the LFP skid operated on diesel fuel for 1919 hours. Additional hours were added to the jet fuel demonstration because during the first 500+ hours of LFP skid operation, LFP skid output was limited to 50% capacity because of insufficient heating by the H-102 process heater. This LFP skid capacity problem limited SOFC operation to 150 amps or about 18 kW. With power and fuel flow rates reduced, the test period was extended to use up the remainder of the jet fuel at the site (1000 gallons total). Prior to the end of the jet fuel test, an additional heater was installed on the skid, and full capacity was achieved. During the diesel fuel portion of the test, the skid was operated at about 75% capacity for most of the test. Only 85% capacity was required to meet the peak power of the SOFC at 27 kW. At the conclusion of the test, about 2500 gallons diesel fuel of the 3000 gallons delivered had been processed by the LFP skid.

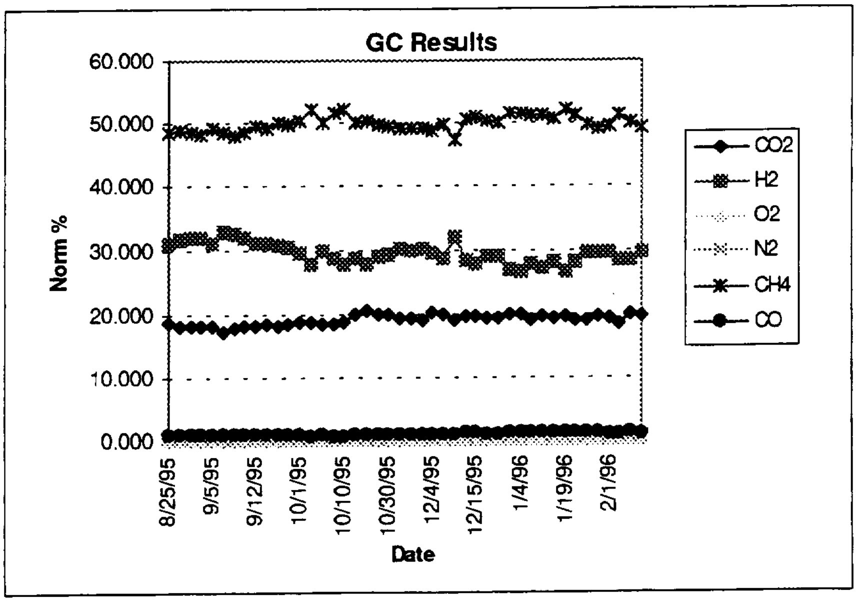
Appendix A provides tabular data which identifies all of the starts and stops of the LFP skid and the SOFC during the demonstration project.

Sulfur in Fuel

Of the 1555 hours of SOFC operation on diesel reformate, 815 hours of operation were with as-received DF-2 containing 277 ppm sulfur and 740 hours of operation were after the 1/5/96 thiophene addition. 73 pounds of thiophene were added to approximately 1500 gallons; thus, the thiophene-doped diesel had a sulfur concentration of 2311 ppm. Of the 1919 hours of LFP operation on diesel, 771 hours were after the 1/5/96 thiophene addition. Following an addition of 13 pounds on 2/2/96; the diesel had a sulfur concentration of 3090 ppm. The LFP was operated for only 191 hours after this addition. Appendix B provides tabulated data of fuel sulfur sample analysis results.

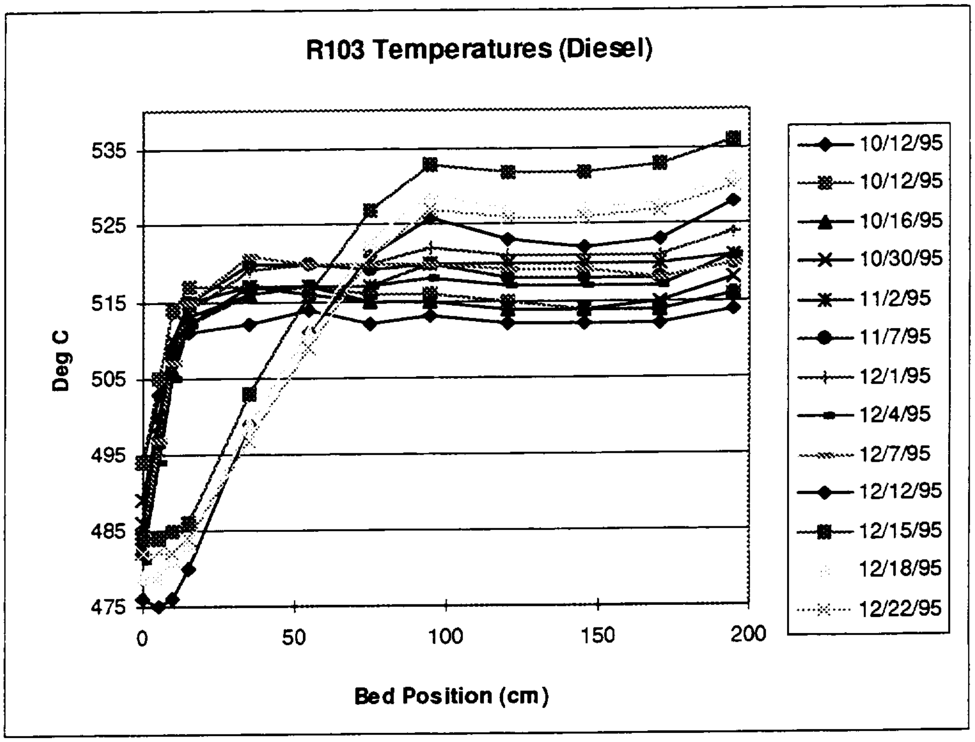
Reformate Constituents

The LFP skid succeeded in producing reformate within specified concentrations. The following graph shows the relative percentage of reformate concentrations as measured by gas chromatography during the project.


GC Results
60.000
50.000
40.000
30.000
20.000
10.000
0.000
Norm %
8/25/95
9/5/95
9/12/95
10/1/95
10/10/95
10/30/95
12/4/95
12/15/95
1/4/96
1/19/96
2/1/96
Date
CO2
H2
O2
N2
CH4
CO

R-103 Temperatures

On 12/7/95 the LFP skid tripped due to a PLC halt. After the restart, the R-103 temperature profile had changed; the drop in upper bed temperatures indicating that the top portion of the catalyst bed had become deactivated. The following graph shows the change in the R-103 temperature profile following the restart.



The next section of this document contains the assessment by the operators of "Lessons Learned" during the project.

Appendix C provides the operator's unabridged chronological journal of project activities and events.

Logistics Fuel Process Demonstration
Lessons Learned

Solid Oxide Fuel Cell

Pnoz Control Setpoint

On some of the start-ups, the flow of NH mix gas remained too high to shift the operating state from LoadP to Run. This condition existed because the NH mix gas flow was sustained to maintain a programmed pressure at the fuel nozzle inlet. The pre-programmed pressure requirement needs to be reevaluated to determine if a lower value can be used so that natural gas by itself can provide sufficient nozzle pressure during a start-up.

Start-up Checklist

C/B-302 reset is not in the start-up check sheet. This circuit breaker interrupts power to natural gas solenoids valves. The breaker will trip if reset before LoadP is enabled. This occurred during a start-up on November 13, 1995. Originally, this circuit breaker interrupted power to a natural gas compressor. When the gas compressor was removed from the SOFC, shutting of the circuit breaker was removed from the start-up check list.

Assembly Problem

On 7/20/95, the SOFC shutdown on low air flow. This condition was caused by a loose hose clamp for a flexible hose at the air blower discharge, which allowed the hose to become detached, resulting in a portion of the air being discharged to the SOFC exhaust hood. This hose was reattached tightly and the problem has not recurred.

SOFC System Ancillary Problems

The SOFC air blower was replaced on two occasions, September 18, 1995 & October 25, 1995, because of excessive noise. The blower did not actually fail, but blower or motor bearing whine caused significant concern with operators. The root cause of the problem has not been identified, but may be due to changes in belt tension or the high temperature operating environment.

The SOFC air heater failed on two occasions, September 28, 1995 & November 6, 1995. Both of these failures were due to burn out of one of the three heater elements.

Initially, the logistics fuel reformate mass flow controller was not properly sized or calibrated. This prevented the smooth transition from operation on natural gas to reformate. This problem was resolved on September 25, 1995 with a new mass flow control valve.

The air flow indication sensor's accuracy degraded and at the time of replacement was indicating lower air flow than actual. This sensor was replaced on December 11, 1996.

Logistics Fuel Processing Skid

Steam Pressure Control

The steam system pressure control during start-up of the steam system was achieved by operation of a manual valve at the discharge of the H-103 series of water heaters. During start-up, the water pump is turned on, the water heaters are turned on, and flow exhausts through the manual valve to a standpipe located off the skid. The valve is open at start-up, and as steam forms, pressure builds up in the system. If pressure builds up too much or too rapidly, the operator may reduce flow, reduce heating or open the throttle valve. All of these have the effect of changing the point within the heaters where boiling occurs and will rapidly and drastically change the saturation conditions within the water heaters. When super heating is achieved, small changes in valve position will cause large swings in pressure and temperature.

When water temperature and pressure are at the desired point (350°C and 27 bar), and other skid parameters are correct, steam is redirected from the steam pipe vent to the reformer via a pressure control valve (PCV-206). This pressure control valve automatically controls the pressure of the steam system after start-up and reformation begins.

A better design would be to have the discharge of the pressure control valve selectable, either ported to the vent or the reformer. This would enable the operator to warm up the steam system more smoothly. The caution is that the steam valve would undergo a severe transient when shifted from discharging from the vent (0 psig) to the reformer (145 psig). This could be easily accomplished by having the operator take manual control during this shift, which he has to do during the present design anyway.

Steam Generation

Consideration should be given to changing the steam generation design concept. The current design is very susceptible to large transients in pressure and temperature. As any parameter is changed (flow, temperature or pressure), the points within the water heaters at which nucleate boiling, bulk boiling and dryout are changed. The result is that only small changes in any of these parameters can be tolerated by the control system or large transients in pressure and temperature will result. Possible improvement may be to have separate boiler section with water level control and super heater section.

Process Flow Strainers/Filters

The LFP skid design was devoid of process stream strainers or filters. This led to operational problems on October 16, 1995, January 7, 1996, January 16, 1996, January 23, 1996 and February 8, 1996.

Scale was noted to have accumulated in the superheat region on the last steam heater element, H-103E. Gritty debris was noted to clog PCV-206 causing pressure transients which resulted in steam pressure trips on October 16, 1995 and January 16, 1996. Also noted that on a skid restart on October 24, 1995 steam valve operation was sluggish. In these cases, we disassembled and cleaned PCV-206 to restore normal operation. This problem was again noted on February 8, 1996, but the transient was corrected by massaging the valve.

The LFP tripped on January 7, 1996 due to a high B-102 water level caused by obstruction of LCV-305 with foreign substances. This condition was noted to occur after the shutdown in September 1995 when level control lines were noted to be plugged solid and required blow out with high pressure nitrogen (2500 psig). Often during start-ups, these level control valves had to be manually cycled between full open and full shut to purge lines of debris which made valve operation sluggish.

On January 23, 1996, flow oscillations in diesel reformate occurred when PCV-314 was unable to maintain 5.5 bar. The problem corrected itself, but was probably due to foreign material restricting flow through the valve. Two inline filters were installed at the site in the process line between the LFP skid and the SOFC.

Electrical Cabinet Pressurization

The electrical cabinet on the skid had a pressurization system which was designed to maintain a positive pressure within the cabinet to prevent flammable or explosive gasses from entering the cabinet. The pressurization system did not work well which resulted in too large pressure swings with changing ambient temperatures. We left the trip overridden during the entire test program. This should more accurately be an alarm since loss of pressure does not automatically result in introduction of flammables into the electrical cabinet. The cabinet also had a vortex cooler which used a large quantity of control air to accomplish very little cooling. This single air load requires a large capacity air source.

Pumps

The water and fuel pumps were positive displacement, motor driven hydraulic-diaphragm pumps. The stroke of the hydraulic piston was effectively controlled by adjusting the point at which hydraulic oil bypasses back to the sump. The pumps dripped oil all over the baseplate of the skid, but amazingly never seemed to require oil additions. A removable and cleanable drip pan should be included in follow-on designs.

Skid start-up was delayed because of large spikes in the water flow indication. A portion of the problem was due to the wiring of the mass flow meters which was fixed with a wiring change directed by the mass flow meter manufacturer. A large portion of the spikes was due to pressure oscillations from the mechanical portion of the pump piston. This was damped by surge suppressors, but additional damping was required with the addition of flex hoses and check valves.

We had one low water flow trip attributable to the water pump. The internal relief of the pump required readjustment. The pumps internal reliefs were not properly set as received.

Insufficient H-102 Capacity

The R-103 reformer has a process heater (H-102) at its inlet. This heater heats incoming steam (330°C), fuel (300°C) and recycle flow (50°C) to 480°C in prior to flowing into R-103. The original heater was rated at 8 kW, 240 VAC. During operations on August 24, 1995 when increasing skid reformate production it was noted that the H-102 heater was only able to handle 50% of design flow when it was at 100% of output. Clamp on ammeter readings verified that the heater elements were drawing full rated power. In September 1995, an additional 480 VAC heater rated at 8 kW was installed in series with the original heater as a field modification. This heater was designated H-104, and enabled operation up to full flow.

H-102/104 Control

After the field modification which added H-104 to augment H-102, the control scheme implemented was to provide the same op signal to both heaters. This signal was generated from a temperature mismatch on a T/C probe at the inlet to the R-103 catalyst bed. The H-104 heater however has a high sheath temperature cutback built into its control scheme, which will cutback it's power output by 40% when its sheath temperature gets too hot. Since H-104 is the downstream heater, it is always the hotter heater. As a result, during a start-up, we would see the heating load on H-102 gradually increase as H-104 would cutback output because of high sheath temperature. Ultimately, this did not turn out to be an operational problem because even though H-102 would indicate that it was at 100% power, increasing load would cool H-104 which would clear its cutback and allow it to pick up load until its sheath overheated again. Operationally it was a little disconcerting because we could not tell by looking at screens how close we were to reaching a capacity limit on these heaters.

During start-up, this heater pair is normally put in manual control to establish a steady ramp rate. When the fluid (nitrogen during start-up) temperature was close to normal operating setpoint, control would be shifted to automatic.

Nitrogen Purge Sources

The nitrogen purge system is used as the fluid medium for heating up the HDS system. The nitrogen was supplied from a regulator on a manifold of cylinders to a single connection on the LFP skid. This single point supplied purge control solenoid valves for the high pressure end (HDS system) and the low pressure end (Reformer, Separators and Compressor). During heatup of the HDS system, the nitrogen solenoid is open, and a steady flow is established through the H-101 fuel heater, the R-101 catalyst bed, and the R-102A & B catalyst beds. The H-101 heater is on as are the catalyst bed heaters.

If nitrogen is required for the low pressure end (in order to make up for nitrogen leakage during heatup of R-103 for example), during the HDS system heatup, then opening the low pressure end solenoid valve will cause a nitrogen pressure transient which reduces the nitrogen flow through the HDS system which will result in overheating H-101 and tripping that heater.

The problem can be resolved by having two entry points on the skid and allowing the site to provide independent nitrogen sources.

H-101 Heater Trips

The H-101 fuel heater is started by establishing a nitrogen flow rate through the heater, heating it and porting the nitrogen through the HDS system. The normal operating setpoint temperature for the fluid (fuel and hydrogen) flowing through this heater is 380°C. Nitrogen flow is established by setting the HDS system operating pressure to 10 bar, and adjusting the nitrogen supply pressure sufficiently higher to cause flow through the system. There is no adequate flow rate indication in this system. Setting the regulator pressure at 12 bar by procedure causes a temperature difference between the fluid and the heater sheath of greater than 100 degrees. A setpoint of about 15 bar causes this temperature difference to drop to about 100 degrees, and higher pressures cause it to reduce a little more. The operating software causes this heater to trip at a sheath temperature of 480°C. With a setpoint of 380°C for the fluid system, the sheath temperature of 480°C is very easily achieved with nitrogen pressures below 15 bar.

Additionally, if nitrogen pressure fluctuates due to other use, a trip will occur very quickly.

During start-up, this heater was normally put in manual control to establish a steady ramp rate. When the fluid (nitrogen during start-up) temperature was close to normal operating setpoint, control would be shifted to automatic.

PCV - 300/313

These valves control recycle flow. PCV-300 controls the recycle flow rate to R-103, and originally PCV-313 was opened to ensure a minimum flow through the recycle compressor in case PCV-300 was shut off. Later it was realized that the flow orifice for the gas compressor was not properly sized and always indicated maximum flow, resulting in PCV-313 always being shut. Consequently, the orifice plate was removed, and the control scheme for PCV-313 was altered to control compressor discharge pressure. Then if PCV-300 shut, pressure would rise, and PCV-313 would open. PCV-313 was normally operated with a setpoint of 28 bar which would provide sufficient pressure for flow requirements through PCV-300.

During start-up, PCV-313 would be in manual and shut, and PCV-300 would be in manual and open allowing a maximum nitrogen flow rate which would increase the heatup rate.

Pressure Control to the Fuel Cell (PCV-314)

When gas flow was established to the fuel cell, the flow path was about 300 feet from the skid to the fuel cell. Normal start-up procedure required a good gas sample prior to shifting fuel from natural gas to reformate. The 300 foot line was required to be purged for the sample. This was accomplished through a manual vent near the fuel cell but outside. This vent remained open until about 30% of the fuel cell's fuel was supplied by reformate. PCV-314 would not be able to control pressure at 5.5 bar unless flow was established through the system. The vent path to atmosphere until fuel was flowing through the fuel cell established the required flow.

Pump Suction Surge Suppressors

The pump suction surge suppressors were never set properly because the set pressure was supposed to be 80% of operating pressure which would have required drawing a small vacuum. This was never important enough to setup a system to set the pressure. We setup level indicators for water and fuel in the pump suction lines. Lacking surge suppressors, the remote level indicators oscillated with every stroke of the pumps. An alternate pressure source than the suction lines would have been better. The low level trips which were associated with these level indicators are probably not required (alarms are adequate) since low flow conditions which result from low levels will cause skid trips.

Water Return Mass Flow

There was a mass flow meter in the water return line from B-102, but not from B-101. B-102 was common to both test sites, but the mass flow controller in just one return line at the Edison site was nearly useless. The flow meter was not used for any control function, just data collection, but without flow from both separators, the data was incomplete. The mass flow meter could have been plumbed to receive the combined flows, but that would have caused a greater design difference between the two sites than already existed.

The one useful function for this mass flow meter was in indicating the effectiveness in cycling the B-102 level control valve to clear buildup of obstructions in the water return line.

Remote Access

The fuel cell is designed for unattended operation, and the control system has remote data acquisition capabilities through a modem line. This capability would have been helpful for the LFP skid. For example, if the skid suffers an I-2 trip without an I-1 trip, then fuel continues to port through the HDS system and condense out in the flare stack. The flare stack has a capacity to collect condensed fuel for about 1.5 days at which point an I-1 trip will occur on high flare stack level. Restarting the HDS system is difficult and should be avoided, so it would be helpful if the operators could remotely determine that an I-2 trip had occurred, and that flare stack draining was needed to prevent an I-1 trip.

The remote monitoring was alleviated to an extent because the fuel cell would alarm if it received an LFP not ready signal. This signal occurred whenever the reformate to fuel cell solenoid valve shuts. This valve shuts on an I-2 trip (An I-1 trip causes an I-2 trip). We setup a remote dialer to call operators if certain alarm conditions on the fuel cell occurred. One of these alarms which would trigger the remote dialer is the LFP not ready alarm. The remote dialler would signal us to call the fuel cell. The fuel cell software would indicate the alarm condition, and if it was the LFP not ready, we would go to the site to see if the LFP suffered an I-1 or I-2 trip.

I-3 trip

The I-3 trip is superfluous. Since an I-3 immediately causes an I-2 trip, the conditions which cause an I-3 trip ought to just cause an I-2 trip.

Hydrogen Flow Control

When hydrogen flow is first started, the R-101 pressure is about 10 bar and the hydrogen supply pressure is about 50 bar. During normal operation R-101 pressure is about 45 bar. The FCV-100 tuning constants that are adequate for the 5 bar differential do not achieve steady hydrogen flow very quickly on start-up. Normally, hydrogen flow was initiated with manual control, and when the desired flow rate was established, a bumpless shift to automatic control always worked very well. It was often the case that tuning constants which were adequate for steady operations were not adequate for start-ups. H-101, H-102/104, PCV-300/313, FCV-100 are the primary examples.

Sequence of Alarms

The Operator interface software would poll the LFP skid PLC every 3 seconds to read data from the data registers. The order in which data registers are read is also the order in which the software records alarms. The time stamp associated with an alarm is the time the operator interface software (Wonderware) writes the data to disk. This design scheme initially made it very difficult to determine the sequence of events which resulted in a trip of the skid. Eventually we learned to interpret the recorded sequence and deduce the sequence of events.

Fuel Channeling

During the outage in September 1995, fuel was noted to have filled the B-101 separator and half filled the B-102 separator. This problem appeared to be less severe later in the demonstration possibly due to other material in R-103 obstructing the channeling.

Flushing Separators

During the September 1995 outage, the water separator tanks were drained and flushed because of fuel found in the tanks. The operators were concerned that they may have overfilled the B-101 separator during the flushing evolution and caused wetting of the bottom portion of the R-103 catalyst bed. The difficulty in flushing these separators is that drain and vent connection penetrations share common piping with the local site glass and remote d/p level transmitters. Dynamic water flow through these penetrations causes loss of level indication. In hindsight, operators should have filled the separator through the drain with the vent open as a guard against overfilling.

Flushing Separators

The control system is inadequate for automatic temperature control during start-up. Setting the target final temperature as the start-up setpoint for heaters H-101, H-102 or H-103 results in tripping these heaters on overtemperature. The large temperature difference will cause a large error signal and full power output. Full power for these heaters on start-up will cause a high sheath temperature and trip. Normally during start-up, manual control was used to set a power level that would cause a steady ramp rate until temperature was close to the final operating temperature. The heaters would be shifted to automatic control then.

Trip Inhibits

Trip inhibits were found to be a necessary feature of the control system. The initial design did not have this feature for most trips; the feature proved to be particularly useful during start-ups. For example, there is a low low separator water level I-2 trip. Normally during a start-up, the levels in the separators are below the trip setpoint, and will remain so until steam condensation occurs after fuel reformation begins. This trip needs to be inhibited to allow start-up.

The high steam pressure trip is not able to be inhibited; transients during start-up of the steam system when venting steam through the manual throttle have caused approaching uncomfortably close to this I-2 trip.

Due to the design of the water tank level indication system at the Edison site, overfilling a water tank results in spilling water to the low pressure side of a d/p level transmitter. This would result in a false low level indication and resultant low level trip. After this event occurred on October 31, 1995, inhibiting this trip became an integral part of the water tank filling procedure.

HDS Start-ups

The start-up of the HDS system appeared to get progressively more difficult and take longer to complete with the increase in hours of operation. The last start-up of the HDS system took 8 hours, earlier in the project the start-up lasted about 5 to 6 hours.

The Adiabatic heaters on R-101 never operated properly, and the other heaters in the HDS system were never finely tuned, normally overshooting temperature setpoints in long slow oscillations.

Recycle Compressor

The recycle compressor is difficult to start up. This compressor is a positive displacement, motor and belt driven, hydraulically operated diaphragm compressor. The diaphragm easily becomes air bound. The operating manual and manufacturer provides a procedure of bleeding air through a bypass valve back to the hydraulic sump. We found that this procedure may require hours of operation before purging air from under the diaphragm. The operators discovered that breaking a mechanical fitting in the compensating oil line to the diaphragm will accelerate the air removal process, and allow full compressor operation in just a few minutes. The details of why this works have not been discussed with the compressor manufacturer.

Fuel Sulfur Content

The mil spec for diesel fuel allows sulfur concentrations up to 3000 ppm. The mil spec diesel delivered at Edison's site had a measured concentration of 277 ppm. In order to demonstrate the sulfur removal capability of the LFP skid, thiophene was added to the diesel fuel to raise the sulfur concentration to 3000 ppm. An addition on January 5, 1996 of 73 pounds of thiophene was calculated to increase the sulfur concention of 1500 gallons of diesel to 3000 ppm, but only raised the concentration to 2311 ppm. Another addition on February 2, 1996 of 13 pounds of thiophene was calculated to increase the sulfur concentration of 800 gallons of diesel to 3300 ppm, but raised the concentration to only 3090 ppm

Operator Errors

On October 23, 1995, single pole heater breakers for H-101 and H-102 were replaced with two pole breakers. Operators inadvertently swapped the H-101 and H-102 heater breakers. This condition was noted during a start-up on December 1, 1996 when the H-102 heater tripped on overcurrent at about 70% capacity.

An operator caused an I-1 trip on January 7, 1996 due to high H-101 temperature. After an I-2 trip, in order to reduce the flare stack fuel condensation rate, the operator reduced fuel flow. He did this too quickly by setting in the desired fuel flow, which resulted in an H-101 high sheath temperature. The flow needs to be reduced in small increments of 0.1 to 0.3 gpm.

An operator tripped the LFP skid on January 19, 1996 when he caused a false high B-102 separator level indication while venting the level d/p cell. Venting of the detector was necessary because an incorrect level was being indicated due to vapor trapped in the cell. The level trips should have been inhibited prior to venting.

Between December 7, 1995 and January 29, 1996 the LFP skid was operated with less than recommended steam flow. In November 1995 a revised LFP skid operating procedure was sent to the Edison site which incorporated lessons learned at the Connecticut site. One of the lessons learned was that methane production would be increased if recycle flow was "maximized." The new procedure was not adopted because methane production at the Edison site was adequate and with-in specification for the calibration of the SOFC reformate mass flow controller. After a start-up on December 7, 1995 it was noted that methane production was down, and the R-103 temperature profile was changed; the first three or four thermocouples indicated no temperature rise as had previously been the case. On consultation with Haldor Topsoe, recycle flow was increased in order to increase the methane production. The new procedure's steam flows were not adopted at the time of increasing recycle flow. This problem was not noted until January 29, 1996 when screen printouts were reviewed by HTI and it was noted that steam flow rates were below values expected for the fuel and recycle flow rates.

LFP Material Problems

General Comment - The skid was delivered in June 1995, but significant material problems delayed start-up. The manufacturer's site (TSCI) did not have sufficient auxiliary systems at the site of assembly and consequently many systems were not tested prior to shipment. During shipment, many fasteners became loose.

Initial Skid Start-up

HTI engineers were on site to start-up the LFP skid in June 1995, but departed prior to start-up because of the many material problems which required correction. During the period July 10 through July 20 the following material problems were corrected or resolved:

Remount mass flow transmitters on rubber mounts,
Adjust PCV-114 and FCV-100 packing to stop hydrogen leaks,
Insulate hot piping and valves to prevent process heat loss and for personnel protection,
Install missing plugs for all transmitters,
Install blocking valves and pressure gages downstream of relief valves to verify reliefs are not leaking,
Remount flow d/p transmitter FT-228,
Plumb station air to be primary source of control air, use the provided compressor as backup,
Reinstall FE-313 orifice plate which was installed backwards,
Replace the R-101 preheater and post heater,
Replace the nitrogen flow to flare stack flow control valve with a needle valve vice ball valve,
Replace SDV-226 with a high temperature valve
Install check valve downstream of SOV-207

Water Heaters

Prior to the return to site by the HTI engineers, Edison personnel tested the steam production system and found the capacity inadequate. Three of five heaters were shorted; two were repairable having frayed insulation at the heater junction box. The third heater required to be replaced having an internal short. This heater had also expanded within its shell which prevented removing just the heater element. The entire shell and heater element had to be replaced. Watlow repaired the heater elements, and TSCI rebuilt the heater shell which required replacement. This problem was resolved on July 28, 1995.

Steam Relief

On August 15, 1995 after HTI personnel returned to site, during start-up of the steam system and initial operation of R-103, the steam relief seat leak stuck open, and would not reset. This relief had a factory setting of 30 bar. Normal operating pressure is 27 bar with a high alarm at 29 bar. An I-2 trip occurs at 35 bar. This valve was replaced on August 17, 1995 by a valve with a 45 bar cracking setpoint. The design pressure of the water system is 45 bar.

Flare Stack Level Switch

A spurious flare stack level alarm occurred on August 10, 1995 due to failure of a magnet switch used to indicate level alarm conditions. This switch was replaced, but later operators learned that the switch can be reset using a hand held magnet.

Seal Welded Threaded Fittings

Fuel leaks were noted subsequent to start-up. These leaks occurred at high pressure high temperature threaded fittings that had not been seal welded. These leaks occurred at the inlet and outlet of H-102; the inlet leak was repaired on August 21, 1995 while maintaining R-103 hot with a N_2 purge. Less severe leaks at the H-102 outlet and taps for a d/p transmitter were repaired during an outage on September 18, 1995.

Flow Oscillations

Both the water and fuel mass flow meters demonstrated oscillations during start-up testing. The water oscillations were reduced on July 21, 1995 with a temporary flex hose and check valve installed at the pump discharge. A low water flow trip due to oscillations occurred on August 23, 1995; this was fixed by lowering the trip setpoint. Permanent flex hoses and check valves were installed and the surge suppressors were adjusted during an outage of September 18, 1995. Fuel flow oscillations were adequately controlled with an electronic dampening adjustment on August 8, 1995.

Oil in Control Air

Following connection of site air to be the main supply of control air in July, it was noted during operation in August that oil was passing through the installed filter system. A coalescing filter was required. During the September outage, a new filter system was installed, and the control air signal transmitters to air operated valves were thoroughly cleaned to remove oil which had come from the air system.

Semi-Planned September Outage

In September, a planned shutdown was conducted for the LFP skid between September 18, 1995 and September 30, 1995. The primary purpose of the outage was to add a heater in series with H-102, to enable the LFP skid to operate at full capacity. During this outage the following additional maintenance activities were accomplished:

Repair of fuel leaks at non-welded threaded fittings,
Change out the top 12" of R103 catalyst
Added permanent flex hoses and check valves to the water system,
Replace an inoperative mass flow controller, Reformate from LFP to SOFC,
Drain and flush fuel from water separators,
Clean out air system components contaminated with oil.
Installed coalescing air filter in control air system.

Water pump internal relief

The water pump internal relief was not set at the factory, and had to be set during start-up. Subsequent to start-up, a low water flow trip occurred on October 2, 1995 which was attributed to drifting of the pump internal relief setpoint.

Thermocouples

Broken thermocouples were noted and replaced:

A broken thermocouple on H-103 prevented heater reset and start-up on October 18, 1995
A broken thermocouple on H-102 prevented heater reset and start-up on November 30, 1995

Single Pole Circuit Breakers

A single pole circuit breaker was installed for heaters H-101 and H-102. These circuit breakers were installed in a 240 VAC center tap circuit. This lead to a problem on October 17, 1995 when a grounded heater element in H-102 continued to draw current after the circuit breaker was opened. A current path existed from the other side of the 240 transformer to ground, creating a 120 VAC circuit. The condition was immediately corrected by securing 240 VAC power to the LFP skid. The fault was corrected by disconnecting the grounded heater element. The design problem was corrected by replacing the single pole circuit breaker with two pole breakers on October 23, 1995.

Failed H-102 and H-101 Heater Elements

The H-102 heater element failed on October 18, 1995 and reduced the capacity of H-102 by half. This condition appeared to be tolerable because with the addition of heater H-104 in September 1995 there appeared to be excess capacity The skid was operated for a short period between October 26 and November 7, 1995. During a start-up on November 14, 1995 recovering R-103 temperature was so sluggish that the start-up was aborted. The disconnected lower heater element was replaced, and the unit was restarted on November 30, 1995. During this start-up it became clear that the sheath temperature thermocouple on the upper element was failing intermittently at high temperatures. A sheath thermocouple from one of the new lower heater elements was wired into the control system, and the LFP skid was restarted without problem. The lower H-102 heater element had become grounded when its sheath had completely corroded through and exposed heater elements to the internal environment of the heater shell. This heater element was returned to TSCI via HTI for analysis.

The H-101 heater element failed and caused an I-1 trip of the LFP on February 2, 1996. The problem was revealed when it was noted that the H-101 circuit breaker had tripped. Attempting to reset caused an immediate retrip. The heater shell was removed, and it was noted that the heater element was short circuited, and the lower 4 inches of the heater shell was coked solid. The heater element had to be chipped out. A spare heater element was on hand because of the H-102 experience. This heater element was satisfactorily installed, and the LFP skid was restarted.

PLC Halts

Two PLC halts were noted to occur. The first occurred on November 16, 1995 while the skid was shutdown. The PLC restarted without action by the operators, and the trip was not adequately resolved; it was not identified as a PLC halt. A subsequent halt recurred on December 7, 1995 while operating; the LFP skid tripped as a result. The halt was due to a communication error between boards within the PLC. All boards were pushed tightly into the backplane, and the problem did not recur.

It was subsequent to the halt on December 7, 1995 that the abnormal R-103 temperature profile was noted.

Fan Bearing Oil

On November 6, 1995, a spray pattern of black droplets which appeared to be oil was noted directly beneath the B-101 fan. This fan draws air from the bottom where the spray pattern was noted and exhausts out the top. The fan axis is vertical. Initially this was believed to be fan motor bearing oil, but continued operation of the fan with comparison in sound characteristics to the B-102 fan caused operators to believe that the fan was adequately lubricated. The fan operated satisfactorily for the remainder of the demonstration, and the spray pattern was not noted to recur.

APPENDIX A

Project Starts and Stops

Logistic Fuel Processing (LFP) for the Westinghouse 27 kW Solid Oxide Fuel Cell

R103 Starts and Stops	Start Date	Hours	Minutes	Stop Date	Hours	Minutes	Duration	Notes
	8/18/95	12	0	8/23/95	15	58	123.97	Water Flow Spike Trip, I-2 Trip, No I-1 Trip
	8/24/95	10	50	9/5/95	13	35	290.75	H-102 CB Trip; I-2 Trip, No I-1 Trip
	9/6/95	16	15	9/18/95	9	0	280.75	Planned Shutdown for H-102 Mod
	9/28/95	13	30	9/28/95	21	8	7.63	Trip on B102 Level, Line plugged, I-3 Trip, I-2 Trip, No I-1
	9/29/95	13	15	10/2/95	0	58	59.72	Steam System Transient Shutdown, Water pump internal relief
	10/3/95	7	30	10/11/95	16	45	201.25	Stop Jet Fuel Use, Start Diesel Use
	10/11/95	16	45	10/16/95	19	19	122.57	Low Steam Pressure Trip; S/D extended - short in H102
	10/26/95	10	45	10/26/95	13	0	2.25	Restarted with H-102/104 @ Reduced Capacity
	10/26/95	9	0	10/31/95	14	15	125.25	Overfill Water Tank, Low Water Level I-2 Trip
	11/1/95	16	15	11/8/95	9	0	160.75	Manual Trip to Replace E-101 Fan Motor
	11/14/95	12	0	11/14/95	13	0	1.00	Aborted Startup because of H-102/H-104 Heater Control
	12/1/95	15	15	12/7/95	11	30	140.25	PLC Halt Trip
	12/11/95	16	0	1/5/96	12	0	596.00	Added Thiophene
	1/5/96	12	0	1/7/96	12	42	48.70	Trip on B102 Level, Line plugged, I-3 Trip, I-2 Trip, I-1 Tripped on Op Error
	1/9/96	16	0	1/16/96	13	13	165.22	Trip on Low Steam Pressure
	1/18/96	13	35	1/19/96	10	15	20.67	Trip on Operator Error
	1/19/96	10	45	2/2/96	19	15	344.50	LFP Trip on H-101 Low Low Temp, CB Tripped, SOFC did not make shift
	2/8/96	14	0	2/16/96	13	40	191.67	LFP Shutdown
Reformer Hours Jet Fuel							964.07	
Reformer Hours Diesel as Received							1148.07	
Reformer Hours Diesel with Thiophene							770.75	
Total Hours							2882.88	

SOFC Starts and Stops	Start Purge Times Date	Hours	Minutes	Stop Date	Hours	Minutes	Duration		Description of Stop Time Event
*	5/23/95	9	0	6/16/95	1	0	568.00		Blower Discharge hose disconnected
*	6/20/95	10	25	7/20/95	0	11	709.77		Approximate Stop Time due to Reuland Failure
*	7/24/95	9	25	7/24/95	10	0	0.58		Blower Belts Too Tight
*	7/25/95	8	45	8/23/95	12	23	699.63		Shift SOFC from NG to LFP (Jet)
	8/23/95	12	23	8/23/95	15	58	3.58		AutoShift SOFC from LFP to NG
	8/23/95	15	58	8/24/95	10	50	18.87		Shift SOFC from NG to LFP (Jet)
	8/24/95	10	50	9/5/95	13	35	290.75		AutoShift SOFC from LFP to NG
	9/5/95	13	35	9/6/95	16	15	26.67		Shift SOFC from NG to LFP (Jet)
	9/6/95	16	15	9/18/95	9	0	280.75		Shift SOFC from LFP to NG for planned LFP Shutdown
	9/18/95	9	0	9/19/95	13	23	28.38		Manual Shutdown, Excessive Blower Noise
*	9/28/95	9	0	9/28/95	16	36	7.60		Open, 1 leg of Pyradia
*	9/30/95	8	0	10/3/95	11	30	75.50		Shift SOFC from NG to LFP (Jet)
	10/3/95	11	30	10/11/95	9	15	189.75		Shift SOFC from LFP to NG during Tank Fill for Diesel
	10/11/95	9	15	10/12/95	9	33	24.30		Shift SOFC from NG to LFP (Diesel)
	10/12/95	9	33	10/16/95	19	19	105.77		AutoShift SOFC from LFP to NG
	10/16/95	19	19	10/25/95	10	52	207.55		Manual Shutdown, Excessive Blower Noise
*	11/6/95	8	40	11/6/95	17	25	8.75		Open, 1 leg of Pyradia
*	11/13/95	10	0	12/1/95	19	15	441.25		Shift SOFC from NG to LFP (Diesel)
	12/1/95	19	15	12/7/95	11	30	136.25		PLC Fault on LFP, SOFC tripped on low volts, failed to shift to PNG
*	12/7/95	13	15	12/12/95	15	0	121.75		Shift SOFC from NG to LFP (Diesel)
	12/12/95	15	0	1/7/96	12	42	621.70		AutoShift SOFC from LFP to NG
	1/7/96	12	42	1/10/96	12	15	71.55		Shift SOFC from NG to LFP (Diesel)
	1/10/96	12	0	1/16/96	13	13	145.22		AutoShift SOFC from LFP to NG
	1/16/96	13	13	1/18/96	18	5	52.74		Shift SOFC from NG to LFP (Diesel)
	1/18/96	18	5	1/19/96	10	15	16.17		AutoShift SOFC from LFP to NG
	1/19/96	10	15	1/19/96	12	15	2.00		Shift SOFC from NG to LFP (Diesel)
	1/19/96	12	15	2/2/96	19	15	343.00		LFP Trip on H-101 Low Low Temp, CB Tripped, SOFC did not make shift
*	2/6/96	8	0	2/8/96	18	0	58.00		Shift SOFC from NG to LFP (Diesel)
	2/8/96	18	0	2/16/96	13	30	187.50		Shift SOFC from LFP (Diesel) to NG
*	2/16/96	13	30	2/19/96	23	45	82.25		Loss of Power (including UPS) Trip
	2/21/96	6	10	2/26/96	8	40	122.50		Final Shutdown
*	Indicates a Startup								
Total hours from Purge							5648.1	hrs	from Purge State
Hours on Natural Gas							3261.0	hrs	
Hours on Jet Fuel							766.0	hrs	
Hours on Diesel Fuel							1555.0	hrs	
Total							5582.0	hrs	

APPENDIX B

Sulfur Analysis Results

Logistic Fuel Processing (LFP) for the Westinghouse 27 kW Solid Oxide Fuel Cell

Sulfur Sample Log & Analysis Results					
Sample Date	Detectable Limit (ppm)	Results	Units	Lab	Notes
Jet					
7/24/95	1	ND		Del Mar	
8/21/95	1	ND		Del Mar	
8/28/95	1	ND		Del Mar	
9/5/95	1	ND		Del Mar	
9/11/95	1	ND		Del Mar	
9/18/95	1	ND		Del Mar	
9/28/95	1	ND		Del Mar	
10/4/95	1	ND		Del Mar	
Diesel					
10/11/95	1	277	ppm	Del Mar	Raw Diesel from Tank, (.028 wt%)
10/12/95	1	14	ppm	Del Mar	From HDS, suspect contaminated sample
10/16/95	1	ND		Del Mar	From HDS, R101 @ 45 bar
10/16/95	1	ND		Del Mar	From HDS, R101 @ 50 bar
10/16/95	1	ND		Del Mar	From HDS, R101 @ 385 Deg C
10/26/95	1	ND		Del Mar	From HDS
10/30/95	1	ND		Del Mar	From HDS
11/6/95	1	1	ppm	Del Mar	From HDS
12/4/95	± 150 ppb	500	ppb	ERC	From HDS
12/12/95	± 150 ppb	0.5	ppm	ERC	From HDS
12/18/95	± 150 ppb	No Results		ERC	From HDS
1/2/96	± 150 ppb	No Results		ERC	From HDS
1/4/96	± 150 ppb	No Results		ERC	From Tank, Prior to Thiophene addition
1/4/96	± 150 ppb	No Results		ERC	From HDS, Prior to Thiophene addition
1/5/96					Added Thiophene
1/11/96	± 150 ppb	No Results		ERC	From Tank, After Thiophene addition
1/11/96	± 150 ppb	1.32	ppm	ERC	From HDS, After Thiophene addition
1/18/96	± 150 ppb	245	ppb	ERC	From HDS
1/23/96	1	2	ppm	Del Mar	From HDS
1/25/96	1	2311	ppm	Del Mar	Raw Diesel from Tank, Adulterated
2/2/96	0.01	0.309	wt%	Del Mar	Raw Diesel from Tank, Adulterated
2/9/96	1	5	ppm	Del Mar	From HDS

APPENDIX C

Operator's Journal

Logistic Fuel Processing (LFP) for the Westinghouse 27 kW Solid Oxide Fuel Cell

6/7/95

LFP Skid arrived on site - landed on Highgrove test pad

Raised Flare stack -

Final Hydrogen Safety inspection conducted by Air Products Safety Engineer - site satisfactory for H2 trailer tanks.

6/8/95 through 6/24/95

Installed auxiliary support systems for LFP including Fuel, Water, Hydrogen, Nitrogen, Instrument Air, Flare Stack, Steam Exhaust, and Process Gas to SOFC. Installed electrical power to LFP Skid including 240 VAC, 480 VAC and 120 VAC UPS. Installed instrumentation cabling from Admin building to Skid, and instruments and cabling from tank level detectors and Flare stack.

6/15/95

Hydrogen trailer installed on site.

6/17/95 - 6/18/95 Weekend - No site work

6/19/95

Continued Aux System Installation

6/20/95

HTI support team and Westinghouse support team arrive on site to begin LFP testing and start-up.

6/21/95

Began Data Taking at Tgen = 1020 to develop V-I characteristic curves for the Westinghouse 27 kW SOFC operating on Natural Gas.

Loaded Catalyst into LFP Skid Reactor Beds.

6/22/95

Continued V-I data collection at Tgen 1020

Continued to Load Catalyst into LFP Skid Reactor Beds.

6/23/95

Continued V-I data collection at Tgen 1020

Auxiliary System Plumbing connections to LFP Skid continues.

Tested operation of fuel pump and water pump.

6/23/95

Began Data collection at Tgen = 1050 to develop V-I characteristic curves for the Westinghouse 30 kW SOFC operating on Natural Gas.

Auxiliary System Plumbing connections to LFP Skid continues.

Purged Flare Stack and started pilot.

6/24/95

Began Data collection at Tgen = 1035 to develop V-I characteristic curves for the Westinghouse 30 kW SOFC operating on Natural Gas.

Conducted Nitrogen Pressure drop test on LFP Skid HP section to 650 psig.

6/25/95

Sunday - No Data Collection

6/26/95

Continued V-I data collection at Tgen 1035

Concern with smell of hydrocarbons from sample port on HDS system, suspected fuel contamination. HTI indicated presulfide treatment of catalyst bed is source of odor.

Pressurized Skid with Hydrogen, found stem leaks on two control valves. Pressurized and heated HDS system with Hydrogen.

6/27/95

Continued V-I data collection at Tgen 1035

Resumed V-I data collection at Tgen 1050

LFP Skid testing continued. System has several material deficiencies which will prevent start-up.

6/28/95

Resumed V-I data collection at Tgen 1035

Resumed V-I data collection at Tgen 1050

6/29/95

Completed V-I data collection - Westinghouse and HTI depart

6/30/95 - 7/4/95

Long July 4th Weekend - No work

7/5/95

SOFC V-I data averaged and plotted

HTI developing plan for correction of LFP Skid deficiencies

7/7/95

LFP skid deficiency plan received

7/10/95 - 7/14/95

Skid deficiencies being corrected.

7/15/95 - 7/16/95

Pressure drop test of skid initiated with H2 as pressure source. Identified four leaks which require repair. System did not hold pressure.

7/17/95 - 7/18/95

Leaks on LFP repaired, repressurized skid, new leak found on heater bottom gasket.

7/19/95

Pressure test completed. Insulated piping, repressurized HP side of LFP with 450 psig of H2, and LP side with 300 psig of N2.

7/20/95

SOFC shutdown due to insufficient air flow. Diagnosis revealed Paxton blower motor binding (about 4000 hours of operation). Replaced with spare blower/motor package, but motor has smaller (11 amp vs. 13) rating. Will start-up on 7/24/95 when Westinghouse will be able to support.

Pressurized HDS system to 45 bar with H2, started heatup, commenced desulfurization test. Secured the HDS system ops to test the safety safety shutdown features, purge to stack and nitrogen purge.

7/21/95

Resumed HDS system ops, and began operational test of steam system. Noted large swings in water flow mass flow meter. Assuaged with temporary flex hoses and check valves. Noted PCV-131 too small to control pressure in R102; valve full open, pressure increasing, need to replace valve or disk and seat. Continued testing throughout the night.

7/22/95

Increased water flow and steam production; water heaters appear unable to produce quantity and quality of steam required. May need to replace heater elements with higher capacity. Secured testing at 2200 will resume on Monday. Sample of HDS taken and sent to Houston for analysis by Del Mar labs.

7/23/95

Sunday - No work

7/24/95

Continued steam testing of water heaters. Was able to produce reduced flow at correct conditions, but then circuit breaker to water heaters tripped. Shutdown and cooldown of skid.

7/25/95

Meg ohm readings on water heater elements revealed heaters B, C & E are grounded.
HDS sample results returned with less than 1 ppm sulphur in fuel from R102.

Restarted SOFC normally to 180 amps.

7/26/95

Removed heater elements C & E. Heater element B was stuck in heater; removed entire heater and sent all back to Watlow, the manufacturer.

7/27/95

One of two A/C compressors for SOFC room failed. Lowered amps to reduce load on power dissipator.

Westinghouse is discussing water heater problem with HTI and TSCI. May require new design concept.

7/28/95

Continued SOFC operations at 120 amps to reduce load on power dissipator.

One of three failed heaters was internally shorted; the remaining two were shorted at power leads. Heaters are planned to be returned to the site by 8/01/95.

7/29/95 -7/30/95

Continued SOFC operations at 120 amps to reduce load on power dissipator. Weekend, no work or operations.

7/31/95

Continued SOFC operations at 120 amps to reduce load on power dissipator.

Initiated N2 purge and started stack pilot. Maintaining positive N2 pressure on LFP Skid (1-5 bar).

8/3/95

Air conditioning repaired; increased SOFC ops to 180 amps.

Heaters received and replaced for LFP steam. After replacement, pressurized steam system with water to 20-30 bar for 30 minutes. Meggared all heaters, and the two heaters not replaced had lower resistance to ground than others. Consulted HTI and Watlow to recommend replacement.

8/4/95

Baked out low meggar heaters for two hours while making low pressure steam. Started up steam production system, was able to make 28 bar, 330 C steam at 38 kg/hr for about 5 minutes before end of day.

8/5-6/95

Weekend - No Work

8/7/95

SOFC operated over the weekend at 180 amps, no problems.

HTI personnel arrived, continued to make steam, started up heaters of HDS system, started flaring fuel and H2 to the flare stack

8/8/95

Flared and steamed overnight without problem. Adjusted tuning constants on controllers to dampen out fuel flow oscillations. Changed dampening constant at Micro-motion controller which dampened oscillations sufficiently to allow cascade control of H2 on fuel flow.

Started up compressor, unable to purge air out, left running overnight with bypass open.

8/9/95

Overnight, steam system tripped on high heater temperature. Possibly, annulus thermocouple moved against heater wall. Reset trip from 450 C to 600 C. Restarted Compressor, had to depressurize LP system to help compensating pump purge hydraulics side of diaphragm with oil. Lab results of HDS sample indicated less than 1 ppm sulfur.

8/10/95

Operated overnight without incident. System tripped on high flare stack level. Level was actually 12 inches, false alarm. Mechanical massage of float indicator, may have caused trip. Unable to reset. Believe backup switch is available. Wired in, alarm cleared.

Pressure degraded on discharge of recycle compressor. After much consultation with manufacturer's rep, bled down LP side, and purged air from compressor diaphragm. Started up okay, repressurized with N2. May be compensating pump problem; operating overnight keeping an eye on it.

8/11/95

Operated overnight without incident. H-101 operated erratically; flare stack level just below 4 feet, gained 4 feet in 15 hours (previously 3 feet in 15 hours). Increased condensation may be due to cooler ambient air or H-101 decreased heat input.

8/12 & 13/95 (Sat & Sun)

No Work

8/14/95 (Mon)

Continued heating up and tuning heaters. All temperatures normal and operating satisfactorily.

8/15/95 (Tues)

Introduced steam and fuel into R-103.

Shutdown because of steam leak through seat of steam relief. Operation was for 1.5 hours. Continued to flare fuel.

8/16/95 (Wed)

Waiting for new steam relief.

8/17/95

Replaced steam relief , and restarted water system.

Introduced steam and fuel to R-103 at 2.8 kg/hr fuel, steam at 20 kg/hr. Everything looks good.

8/18/95

Continuing to operate LFP skid, increased fuel flow to 3.3 kg/hr with steam at 20 kg/hr and H2 flow ratio control.

8/19/95

Took gas samples indicate 50% CH4 and 30% H2, Remainder CO and CO2. Everything looks good for switch over next week.

8/20/95

Sunday, left operating unattended.

8/21/95

Everything operating as before.

Gas samples indicate 53% CH4 and 28% H2, Remainder CO and CO2.

Small fuel leak at inlet to H-102 required shut down, and purge of low pressure end for weld repair. Kept R-103 and H-102 as hot as possible (> 400 deg F) with small N2 pressure applied. Repressurized low pressure end with 7.0 bar N2 when repair complete. Ran compressor and H-102 and R-103 heaters (less start-up) overnight to restore op temperatures.

8/23/95

Everything operating as before.

Gas samples good. Shifted SOFC to LFP for fuel source at 150 amps. Noted bypass control unstable at high % of load, had to take bypass valve off scan. LFP skid tripped on low steam flow due to water steam flow oscillations (Trend screen printout available showing spikes). The SOFC shifted back to natural gas automatically without problem.

8/24/95

Skid restarted. Shifted SOFC to LFP for fuel source at 150 amps; again bypass control unstable at high %power, had to take bypass valve off scan. The skid is limited to about 50% capacity due to H-102 heater limit. At 20 kg/hr steam flow, 8.3 kg/hr recycle and 3.3 kg/hr fuel, heater is at about 97% of capacity. Westinghouse and HTI informed to resolve.

9/5/95

Skid tripped on R103 inlet low low temperature; no I-1 trip. CB-21 (heater H-102 circuit breaker) tripped. Unable to restart because lock in alarms prevented reset. Reprogrammed LFP ladder logic via phonecon with Ed Loh of TSCI. Conducted warm up of R-103.

9/6/95

Restarted Skid; shifted SOFC to LFP.

9/18/95

Shutdown LFP Skid for scheduled maintenance; continued operation of SOFC on natural gas. SOFC has 575 hours of operation on jet fuel. Plan to restart skid on about 9/30 following accomplishment of maintenance items. Major item is to add an additional heater (480 VAC) to heater H-102. New heater will be designated H-104 and will double capacity. Also repairing observed fuel leaks, change out top 12" or R103 catalyst, replaced LFP to SOFC mass flow meter, and other minor maintenance items.

9/19/95

Noted high metallic whine from vicinity of LFP air blower. On Westinghouse recommendation, shutdown and cool down SOFC.

9/20/95

Went to Preop of SOFC.

9/25/95

During shutdown noted that jet fuel had filled B-102 and half of B-101. Problem is attributed to channeling of fuel through R-103. HTI and Westinghouse informed of problem; no corrective action planned. During drain and flush lost level indication in B101 and may have overfilled and wetted bottom of R103 catalyst bed.

Westinghouse personnel on site (Makiel and Evans). Replaced air blower and motor.

Changed site transformer tap settings. Begin modification to LFP mass flow controller.

9/28/95

Westinghouse completed modifications to mass flow controller. Started SOFC on natural gas. Shutdown SOFC due to air heater problem; noted one leg of heater open circuited.

9/29/95

Restarted LFP skid. Made good gas to the flare stack.

Replaced SOFC air heater.

9/30/95

Restarted the SOFC on natural gas; increase amps to 150.

10/01/95

Operating steady as before.

10/02/95

LFP Skid tripped on steam transient during the previous night. Westinghouse suspects water in steam system flashing and causing transients in pressure. Turns out that water pump internal relief setpoint had drifted and was corrected by resetting.

10/03/95

Restarted LFP skid. Made good gas to the flare stack. Noted smell of jet fuel in GC sample.

Ramp LFP up to 100% output, H-102/H-104 heater ops good.

Switched SOFC to LFP at 150 amps. Commenced V-I curves. Bypass automatic pressure control good.

10/04/95

During SOFC V-I curves, ran SOFC up to 27 kW internal power, 26.2 kW to load bank.

10/05/95

Westinghouse visit completed. Operating SOFC at 140 amps and LFP at 50% capacity to conserve jet fuel.

10/11/95

Received 3000 gallons of diesel fuel at 1000 AM; about 195 gallons of jet fuel left in tank. Calculate that skid starts receiving diesel at 1600. Drew sample of diesel at tank and sent to Del Mar Analytical for sulfur analysis.

10/12/95

Drew sample from HDS and sent to Del Mar Analytical for sulfur analysis. GC results indicate that LFP is making in spec gas, SOFC operating normally at 180 amps.

10/13/95

SOFC operating normally at 180 amps & LFP on Diesel at about 75% capacity (24 kg/hr steam).

10/14 - 10/15/95 weekend

10/16/95

SOFC operating normally at 180 amps & LFP on Diesel at about 75% capacity (24 kg/hr steam). Received sample results from Del Mar, raw diesel 277 ppm, HDS diesel 14 ppm; notified HTI and drew 3 more samples. One without any change from HDS, then with raised pressure to 45 bar, and then one with raised temperature to 385 C.

10/17/95

LFP skid suffered I-2 tripped on low steam pressure transient at 1919 on 10/16/95. While skid is down, drained separators, B101 had about 6 gallons of water & 1/2 gallon of fuel, B102 had about 3 gallons of water and 1/4 gallon of fuel.

During preparations to restart the LFP, noted that heater H-102/H-104 would not reset, and H-215 was achieving OT shutdowns when the skid is tripped! Further troubleshooting revealed that CB-21 is a single pole breaker in a 240 VAC circuit with a center tap grounded neutral. A short in H-102 or H-104 will cause current flow from the unbreakered side of the 240 to the neutral, effectively making unshorted heater elements operate at 120 VAC. Tripped I-1 then opened 240 VAC to isolate fault.

10/18/95

Isolated ground to lower two elements in H-102. Each heater has two legs. Each of the lower heaters had infinite resistance leg to leg, and infinite resistance on one leg to ground. The other leg's resistance to ground was 1.4 kohm on one heater and 198 kohm on the other. Resistance to ground should be infinite to ground and 32 ohms leg to leg. These heater elements will remain disconnected, and operation without them will be attempted. The H-102/104 heater capacity is now about 8kW + 8kW/2 = 12 kW.

New problem, TE-205 failed. This is the T/C for the H-103 Heater OT Trip. This heater cannot be reset with this element failed. HTI informed and requested to provide new TE. TSCI will send UPS red to arrive on 10/20/95.

Sample results in with ND sulfur from 3 samples. Conjecture that 14 ppm was contaminated by the 277 ppm sample.

10/19/95

New two pole breakers arrived for H-101 and H-103. Electrician not available until 10/23/95 to install.

10/20/95

New T/C for H-103 arrived. Auckland not on site, so no direction on replacement activities.

Noted increase in air blower noise on SOFC, similar to last blower.

10/21 & 10/22 Weekend

10/23/96

Replaced H-103 High Temperature S/D T/C. T/C broke off in fitting, had to pull entire heater element (E) to retrieve T/C. Needed electrician to reconnect heater H-103E to 480 VAC. Noted that scale had accumulated unevenly on about 25% of heater element E to a thickness of 1-3 mils. Cleaned off before reinstallation.

Electrician not available in AM, had to wait for PM to get new two pole breakers installed for H-101 and H-102. Reinstalled new two pole CB's, and reconnected H-103 heater E. Will commence heatup of HDS and R103 tomorrow, after testing operation of PCV-206.

Blower noise appears to have increased.

10/24/95

Stroked PCV-206, observed full motion of travel though sluggish. Stroked several times and sluggish ops cleared up. Commenced Heatup of HDS section. Pressurized LP end, and started and vented compressor. Noted pressure increase on steam pressure transducer, concluded that PCV-206 has blockage. Secured heatup, and depressurized low pressure end. Removed and disassembled PCV-206. Observed gritty sand or glass like bits approximately 1/32" to 1/16" long and slivered with smaller diameter. Lapped valve and reassembled and tested IAW manufacturer's procedures.

Blower Noise increased further

10/25/95

Reinstalled PCV-206 and restarted heatup of skid.

Blower noise increased again, Westinghouse directed shutdown and replace blower with one from Paxton which will arrive on 10/30/95.

10/26/95

Restarted skid after heatup. The H-102/104 heater was at 97% output with 20 kg/hr steam, 3.3 kg/hr fuel and 8.3 kg/hr recirc. The problem may be that H-104 is cutting back because of high sheath temperature. Clamp on ammeter indicates H-104 drawing 3 amps per leg, and H-102 is drawing 15 amps. TSCI response is to just increase flow on system which will force H-104 to pickup load.

Placed SOFC in Preop after normal cooldown, and began removing blower.

10/27/95

Skid operated normally at 60% load.

SOFC in Preop waiting for new blower

10/28 - 10/29/95

Weekend

10/30/95

Skid operated fine at 60% throughout weekend. GC results within spec. R103 temperatures look okay.

SOFC in Preop waiting for new blower. Activated charcoal beds for Hoffman cabinet arrived today. Have procedure from Makiel for replacing.

10/31/95

Increased LFP skid output in 5% steps from 60% to 90%; appears to operate okay despite lack of accurate heater ouput indication for H-104. LFP skid can probably support 27 kW SOFC ops at this level.

SOFC in Preop, still waiting for new blower. Replaced activated charcoal beds in Hoffman cabinet.

While replacing Hoffman charcoal beds, overflowed pure water tank which caused a low level trip (I-2) of the LFP skid. Purged LP end with N2, recovered steam system, and reduced fuel flow to HDS.

11/1/95

UPS delivered blower to wrong address. Will retrieve and recover.

Repressurized LP end of LFP skid, started compressor and started heatup of R103. Steam system operated fine overnight at 13 bars through manual throttle.

Restarted the LFP skid at 50% capacity. Received the SOFC air blower from UPS.

11/2/95

Increased LFP skid to 70% in 5% increments.

Connected the old motor to the new blower. Installed blower into the enclosure.

11/3/95

No change on LFP skid at 70%.

Reconnected electrical on the SOFC blower, added T/C sensors.

11/4 - 11/5/95

Weekend

11/6/95

No change on LFP skid at 70%, except noted oil spray pattern under E-101 fan. Called HTI to describe pattern, suspect motor bearing loss of lubrication.

Started Heatup of SOFC. Interrupted Heatup for 30 minutes to adjust blower belt tension.

Aborted heatup, went into cooldown because of burned element in air heater. Westinghouse advised, will send new heater ASAP.

11/7/95

No change on LFP skid at 70%. HTI called to report that they concur that oil is from E-101 fan motor bearing and sent a list of vendors to repair this warranty item.

Went into Preop on SOFC.

11/8/95

Shutdown LFP skid to prep for motor removal. Began motor removal, but JRL noted that there was no discernible difference in ops between E-101 and E-102. Wait for Elgin Moss decision.

Received new heater for SOFC, pulled old heater, need to modify hold down tabs on SOFC or new heater to make fit up.

11/9/95

Heater modification complete, continued reinstallation of SOFC air heater. Photos of old damaged heater available (11/27.95 FAX to W)

11/10/95

Continued reinstallation of SOFC air heater.

11/11-11/12/95

Weekend - No Work

11/13/95

During start-up of fuel cell suffered low NG flow - low string voltage trip. Operator error, circuit breaker 302 was in tripped position, preventing operation of NG solenoids; went back to heat. Resumed start-up; noted that pnoz was controlling low during LoadP (called for 0.99 and was borderline alarm at 0.75); called Makiel at home. When got into Run, pnoz was able to control at setpoint. Operated at 120 Amps on natural gas.

During heatup of LFP skid on nitrogen, noted that the op set point of H-102 drifted up which appeared to be H-104 shifting load from itself to H-102; this seems to be an inherent control problem with these two heaters operating in series from the same T/C; no load sharing capability. This problem was previously observed on 10/25 & 10/26.

11/14/95

Attempted to start-up the LFP skid, but when steam was cut into R-103, severe temperature transient occurred. Was using revised procedure from HTI which suggested reducing back end pressure. Noted that this reduced mass flow through H-102/104 to cause high sheath temperature trip on H-102/104. Attempted to recover temperature from 350 degrees in R-103 for about 1 hour, got up to 400, but heater resumed tripping on high sheath temperature, assumed some other problem exists with H-102/104 and aborted start-up. HTI notified of heater control and capacity problem. Voice mail left with Makiel.

Increased SOFC op point to 150 amps on natural gas.

11/15/95

Removed H-102, upper heater elements meggar sat at > 2 Megohm each, one upper heater element appears to have a failed T/C. Review of Alarms 1 screen revealed that 3 intermittent (short duration) T/C element failures occurred during start-up attempt.

Increased load on SOFC to 180 amps on PNG.

11/16/95

The skid received loss of UPS, high flare level, loss of control air and other UPS related alarms at 0324 this morning. At 0940, the fuse in this circuit was removed and found to be okay. Upon reinstallation and restoration of power, all alarms cleared. This problem was not satisfactorily resolved (This turned out to be a temporary PLC halt). The H-102 heater remains on the workbench awaiting new heater elements. While out, the OTE - 215 T/C fail alarm is normal, but unexplicably it sometimes clears (the T/C is on the workbench, wiring is open).

The SOFC continues to operate on natural gas at 180 amps.

11/17/95

New heater elements arrived, old heater disassembled. What and how to reassemble is now clear.

11/18 - 11/19/95

Weekend - No Work

11/20/95

Welded new heater fittings to bottom flange. Photos of failed heater and new heater available (11/28 FAX to W)

11/21 - 11/26/95

Site stand down for Thanksgiving.

11/27/95

Reassembled H-102 heater, pressure tested with NH mix to 30 bar.

The SOFC continues to operate on natural gas at 180 amps.

11/28/95

Meggar reading of new H-102 heater element indicated low (0 ohm) insulation resistance to ground. Called and informed HTI; conference call with TSCI indicates problem may be moisture and bake out will fix. Will bake out overnight. Narrowed intermittent T/C - 215 OTE failure alarms to wiring between T/C and PLC. Will using alternate wiring from lower T/C in H-102 for PLC input.

The SOFC continues to operate on natural gas at 180 amps.

11/29/95

Bakeout of new H-102 heater element successful, new resistance to ground reading infinite. Reinstalled new heater. Pressure tested system to 20 bar, tightened one Swedgelok fitting at inlet to H-102. Commenced Nitrogen purge.

The SOFC continues to operate on natural gas at 180 amps.

11/30/95

Completed Nitrogen purge. Commenced heatup of HDS and R-103. During heatup of R103, OTE-215 T/C failure alarm occurred. Wired H-102 temperature indicator #215 to one of the new T/C in lower heater element. Resumed heatup.

The SOFC continues to operate on natural gas at 180 amps.

12/01/95

Continued heatup of HDS, R-103 at operating temperature. Started up steam system. Noted that during start-up of fuel flow through HDS system, heatup stopped, top of R102B indication pegged high while bottom dropped to 312 C. After a couple of hours of continued flow, the apparent blockage of gas flow in R102B cleared, and heatup continued.

At 1500 started steam and fuel flow to R-103, new heater handled surge no problem, but later during ramp up to 22.7 kg/hr steam, H-102 C/B 21 tripped. Took manual control of H-102 and reset C/B, temperature restored sat. Noted that C/B 21 and C/B 20 were swapped (21 was 20 amp and should be 40,20 was 40 amp and should be 20). See 10/23/95 entry regarding replacement of single pole breakers with two pole breakers. During this replacement, the breakers were swapped.

Shifted the SOFC to operate on LFP reformate (diesel) at 1900 at 180 amps.

12/02 - 12/03/95

Weekend - No Work

12/04/95

Reported to all parties problem regarding C/B-21 and C/B-20 swap. All agreed to do nothing now, but continue operation to accumulate op hours. Next opportunity breakers will be reswapped.

The SOFC continues to operate on diesel reformate at 180 amps.

12/05/95

LFP operating as before at about 60% capacity, diesel reformate to SOFC.

The SOFC continues to operate on diesel reformate at 180 amps.

12/06/95

LFP operating as before at about 60% capacity, diesel reformate to SOFC.

The SOFC continues to operate on diesel reformate at 180 amps.

12/07/95

LFP tripped at 1130, PLC halted apparently from loss of power. Called Ed Loh at TSCI who suggested looking for loose connections in neutral circuitry. Found stray 60 VAC induced on 240 VAC circuit which cleared when 480 secured. This also restarted the PLC. Thought this cleared the problem, but this turned out to be a red herring and unrelated.

The SOFC failed to make the shift to PNG on the LFP trip at 1130, and tripped itself on low string voltage. Restarted SOFC on PNG, LoadP at 1345 and Run at 1415. Ramped up to 180 amps.

12/08/95

0800 began heatup of skid. PLC halted again at 1025. Called Haldor Topsoe and TSCI. Isolated problem to PLC; Error 19002 communication error between Rack 1 Slot 1, Main processor board and Slot 2. Checked all connections and pushed in all cards. All appeared to be tight. Powered down and up PLC, control system up and operating, but too late to start-up until Monday.

The SOFC continues to operate on natural gas at 180 amps.

12/09 - 12/10/95

Weekend - No Work

12/11/95

At 0700 start LFP heatup. Started Reformation at 1600.

The SOFC operating on natural gas at 180 amps demonstrated increase in VFD percent. At Westinghouse request, lowered amps to 170 to reduce air flow and VFD load. Will investigate problem, may be blower temperature related, obstruction in air flow path, loss of discharge air, or indication problem.

12/12/95

LFP operating at about 60%, R-103 temperature profile bad. First 4 temperatures flat. HTI informed.

The SOFC operating on natural gas at 170 amps. VFD still erratic, currently varying between 89% and 99% with blower exit pressure 63 " to 76". Westinghouse informed.

At HTI recommendation, increased recycle flow to 15 kg/hr and H-102 setpoint to 485; also increased LFP output to 70%. Sample at 1400 indicated that gas is in spec.

Westinghouse decided that cause of erratic VFD is bad air flow sensor, increased amps to 180.

Shifted SOFC to LFP at 180 amps at 1500.

12/13/95

LFP operating at about 70%, R-103 temperature profile not improved. Possible causes include too rapid start-up of HDS system, or last trip with PLC halt was abnormal which caused gum of R-103 and failure of SOFC to shift to PNG.

The SOFC operating on diesel reformate at 180 amps.

12/14/95

LFP operating at about 70%, R-103 temperature profile not improved.

The SOFC operating on diesel reformate at 180 amps.

The site's phones are out due to an auto and train accident; No modem connections.

12/15/95

LFP operating at about 70%, R-103 temperature profile not improved.

The SOFC operating on diesel reformate at 180 amps.

12/16 - 12/17/95

Weekend - No Work

12/18/95

LFP operating at about 70%.

The SOFC operating on diesel reformate at 180 amps.

Phones were restored, but the SOFC modem line is the incorrect phone number.

12/19/95

LFP operating at about 70%.

The SOFC operating on diesel reformate at 180 amps.

Jury rigged the phones to assign a new number to the SOFC modems, 8214 changed to 2936.

12/20/95

LFP operating at about 70%.

The SOFC operating on diesel reformate at 180 amps.

12/21/95

LFP operating at about 70%.

The SOFC operating on diesel reformate at 180 amps

12/21/95

LFP operating at about 70%.

The SOFC operating on diesel reformate at 180 amps.

12/22/95

LFP operating at about 70%. Filled Water tanks, put full tank on service, received Hydrogen trailer bump in prep for Holiday Season.

The SOFC operating on diesel reformate at 180 amps.

12/23/95 - 1/1/96

LFP operating at about 70%.

The SOFC operating on diesel reformate at 180 amps.

Site vacated by personnel for Holidays; called everyday for modem reports.

1/2/96

Returned from Holidays, everything as before; On service water tank at 200 gallons down from 450, and Hydrogen at 1500 psig down from 2050.

LFP operating at about 70%.

The SOFC operating on diesel reformate at 180 amps.

1/3/96

LFP operating at about 70%.

The SOFC operating on diesel reformate at 180 amps.

1/4/96

Ramped LFP up to about 85% capacity.

The SOFC operating on diesel reformate at 180 amps. In afternoon, increased SOFC output to 27 kW internal at 220 amps, Tgen 1050. Then returned to 180 amps at Tgen 1050.

1/5/96

LFP operating at about 85%. Added 73 pounds of thiophene to 1500 gallons in the diesel tank. This was mixed using a transfer pump to establish a vortex in the tank. The thiophene was added using a metering pump into the top of the tank.

The SOFC operating on diesel reformate at 180 amps.

1/6/96 - 1/7/96

Weekend no one working at site

LFP operating at about 85%. Logs indicate that B-102 alarmed on High Level at 1045 on 1/6, and I-2 tripped at 1242 on 1/7. On 1/7 at 1500 operators decreased fuel flow from 5.4 kg/hr to 4.5 kg/hr which was too rapid a decrease and caused H-101 to trip on OT which caused an I-1 trip. The B-102 water return line appears to be restricted and was not able to flow the required amount to maintain a steady level.

The SOFC was operating on diesel reformate at 180 amps until the time of the LFP trip when it switched to natural gas.

1/8/96

LFP shutdown. Ordered Nitrogen and disconnected the B-102 drain to clear the restriction.

Nitrogen arrived late in the day. Cleaned LCV-305 (B-102 Level Control) and readjusted lift point to 3 psig. In retrospect should have left it at 4 psig since control air operates between 5 and 17 psig instead of the 3-15 spec.

The SOFC operating on natural gas at 180 amps.

1/9/96

Began heat up of LFP at 0700. At 1600 started steam and fuel flow to reformer. H-102 appeared to be less quick in recovering from the transient. Stepped output up to 60% by 1800 then left for evening.

The SOFC operating on natural gas at 180 amps.

1/10/96

Increased LFP output to 70%. H-102 output up to 95-99%, clamp on amp meter readings indicate one element pair drawing 11.5 amps and the other 13.5 amps, input to SCR is 24-26 amps at 240 VAC.

Replaced the air flow meter in 20 minutes. . Replaced the air flow sensor while operating by taking air flow off scan and setting to lower value than setpoint. This kept VFD at 100%. Immediately upon restoration of sensor, VFD dropped to about 89%. Shifted the SOFC to operating on diesel reformate at 180 amps at noon.

1/11/96

LFP operating at about 70%.

The SOFC operating on diesel reformate at 180 amps. Took GC and Bellows meter readings for Makiel.

1/12/96

LFP operating at about 70%.

The SOFC operating on diesel reformate at 180 amps.

Makiel correctly identified disparity between bellows meter readings & MFC to be due to external leak. We found three, will repair next week.

1/13/96 - 1/14/96

Weekend no one working at site

1/15/96

LFP operating at about 70%.

The SOFC operating on diesel reformate at 180 amps.

1/16/96

LFP operating at about 70%.

Noted during review of GC results and R-103 temperature profile, degradation in temperature at the 35 cm & 55 cm T/C probes, down 5 deg C each. HTI informed & W informed.

LFP tripped at 1313 on low steam pressure. This was an I-2 trip, continued to fuel the HDS system to flare stack. Allowed LP end to purge with N2 overnight.

The SOFC operating on diesel reformate at 180 amps.

Tightened two of the leaking fittings in the diesel reformate, Hoffman cabinet and building elbow.

The SOFC shifted to NG without problem.

1/17/96

LFP operating at about minimum fuel throught HDS. LP end purged.

Removed PCV-206 the steam pressure control valve. Conducted bench test before opening valve. Noted that the valve was seated. Had suspected that obstruction had prevented closure which caused loss of pressure. Open valve with 400 psig N2 at valve inlet; Noted that the valve stroked properly from shut to full open with 4 to 15 psig air. At full open, noted some obstruction which intermittently choked flow.

Disassembled and inspected valve. Did not note any large obstructions, but thoroughly cleaned and reassembled valve. Conducted another bench test and noted perfect operation. Reinstalled valve and repressurized LP end to 5 bar.

The SOFC operating on PNG at 180 amps.

1/18/96

Warmed up LFP LP end and started steam system. Started reforming at 1335. Increased LFP gas production to 70% to support 180 amps. During start-up noted that B-102 LCV had to be cycled to clear a restriction in flow.

The SOFC operating on PNG at 180 amps.

Shifted SOFC to diesel reformate at 1805.

1/19/96

LFP operating at about 70%. Noted that the B-101 was controlling level very well, but seemed to pass water more easily than previous ops. Valve opens to about 30% then shuts about every ten minutes instead of finding a good steady operating position.

Some operators in troubleshooting this problem correctly identified the problem as the level detector needing venting, however upon venting, the separator level pegged high and tripped the LFP skid at 1015. The skid was quickly recovered, and a good gas sample was obtained at 1130.

The SOFC operating on diesel reformate at 180 amps.

The SOFC shifted to PNG at 1015 when the LFP skid was tripped. The SOFC was shifted back to diesel reformate between 1145 and 1215.

1/20/96 - 1/21/96

Weekend no one working at site

1/22/96

LFP operating at about 70%.

The SOFC operating on diesel reformate at 180 amps. Concern about lowered power output (22.2 kW vice 22.8 kW) prompted query of Westinghouse for analysis. Thought possibly low air flow because of large temperature changes exhibited in stack top to bottom, but cal check of LFP MFC with bellows meter revealed that MFC is 1.5% higher than actual instead of 1.5% lower than actual. This 3% decrease in fuel flow accounts for the temperature profile change and lower volts and lower power output.

1/23/96

LFP operating at about 70%.

The SOFC operating on diesel reformate at 180 amps. At about 0450 through 0530 frequent low flow alarms occurred, diesel reformate MFC flow dropped from 121.5 to 190 slpm, the difference made up by PNG. Increased skid output to 75% in case low flow was due to lack of skid capacity. Review of LFP skid op data revealed that during this time period, the PCV-314 was unable to maintain 5.5 bar in the fuel to SOFC line. This pressure control valve is of similar design as the level control valves and steam control valves which have had problems due to restrictions from foreign objects. (Have printout of data available, 1/23/96 FAX to W).

1/24/96

LFP operating at about 75%.

The SOFC operating on diesel reformate at 180 amps and 22.2 kW

1/25/96

LFP operating at about 75%.

The SOFC operating on diesel reformate at 180 amps and 22.2 kW

1/26/96

LFP operating at about 75%.

The SOFC operating on diesel reformate at 180 amps and 22.2 kW

1/27/96 - 1/28/96

Weekend no one working at site

1/29/96

LFP operating at about 75%. HTI noted that steam flow was low compared to Nov 95 op table values. The LFP had been operating by the Sep 95 op table values, and thus had been operating at too low a steam rate since recycle flow had been increased on 12/12/95. Steam flow was increased from 26.7 kg/hr to 28.3 kg/hr.

The SOFC operating on diesel reformate at 180 amps and 22.1 kW.

1/30/96

LFP operating at about 75%.

Late this afternoon received sulfur analysis result from Del Mar Analytical indicating the tank is adulterated to 2311 ppm. Voice mail left with M. Piwetz at HTI informing of problem; suspect settling of mixing.

The SOFC operating on diesel reformate at 180 amps and 22.1 kW.

1/31/96

LFP operating at about 75%.

The SOFC operating on diesel reformate at 180 amps and 22.1 kW.

2/1/96

LFP operating at about 75%.

The SOFC operating on diesel reformate at 180 amps and 22.1 kW.

2/2/96

LFP operating at about 75%. Added an additional 13 lbs of thiophene to diesel tank.

At 1915, the LFP skid tripped on low Diesel Hydrogen mixture temperature.

The SOFC operating on diesel reformate at 180 amps and 22.1 kW.

The SOFC failed to make the shift to natural gas, went into cooldown.

2/3/96 - 2/4/96

Weekend no one working at site

2/5/96

LFP inspection revealed that the H-101 heater was coked solid in the bottom 4.5" of the heater shell.

Westinghouse uploaded program change to improve shift of SOFC to natural gas on trip of LFP. Change involves not immediately shutting LFP solenoids which will allow residual reformate in line to provide some fuel during shift. Waiting to replenish gas inventory before restarting the SOFC.

2/6/96

Cleaned up H-101 heater, received T/C, drilled and tapped H-101 heater flange for T/C.

Restarted the SOFC on natural gas; start-up normal increased output to 180 amps.

2/7/96

Reassembled H-101 and pressure tested HDS system, then purged system prior to start up of HDS. Started up HDS system.

Noted that generator temperatures were down. On request of Westinghouse, raised stoichs to increase generator temperature.

2/8/96

Noted that H-101 tuning constants were not controlling steady, T varied between 370 and 390. Readjusted tuning constants. Started up remainder of skid, started reforming at 1400. Shifted reformate to SOFC at 1800. During start-up noted that PCV-306 was being obstructed, massaged valve body and apparently passed two small obstructions. Steam pressure controlling normally now.

SOFC operating at 180 amps on PNG. Shifted to diesel reformate.

2/9/96

LFP operating at 75% capacity.

SOFC operating at 180 amps on diesel reformate.

2/10/96 - 2/11/96

Weekend no one working at site

2/12/96

LFP operating at 75% capacity.

SOFC operating at 180 amps on diesel reformate.

2/13/96

LFP operating at 75% capacity.

SOFC operating at 180 amps on diesel reformate.

2/14/96

LFP operating at 75% capacity.

SOFC operating at 180 amps on diesel reformate. Completed 1500 hour diesel reformate test at 0700 this morning.

2/15/96

LFP operating at 75% capacity. Increased output to 80% for V-I curve data collection.

SOFC operating at 180 amps on diesel reformate. Increased Tgen to 1035, stabilized 2 hours and took V-I data. Decreased amps to 160, stabilized 2 hours and took V-I data. Decreased amps to 140, stabilized 2 hours and took V-I data. Restored to 180 amps for the evening.

2/16/96

Increased LFP output from 80% to 85% capacity. At 1340 at the completion of V-I data collection, tripped the LFP skid.

SOFC operating at 180 amps at Tgen 1035 on diesel reformate. Increased amps to 200, stabilized 2 hours and took V-I data. Increased Tgen to 1050, increased amps to 220, stabilized 2 hours and took V-I data. Completed V-I data taking, reduced Tgen to 1020 and amps to 180. Shifted SOFC to natural gas at 1330.

2/17/96 - 2/19/96

President's Day Holiday Weekend; no one working at site. At 2339 on 2/19, Loss of 12 kV line to site resulted in loss of UPS and SOFC stop at 2344. After two hours unit went into cool.

2/20/96

Disconnecting LFP support systems

SOFC shutdown in cool on aux pump; shifted to stop and put back in cool to start blower. Placed SOFC in preop

2/21/96

Disconnecting LFP support systems

SOFC in purge then in heat for restart.

2/22/96

Disconnecting LFP support systems

Conducted V-I curve data collection on natural gas.

2/23/96

Disconnecting LFP support systems

Conducted V-I curve data collection on natural gas.

2/24/96 - 2/25/96

Weekend no one working at site. SOFC operating on natural gas at 180 amps, Tgen 1020.

2/26/96

Disconnecting LFP support systems

Shutdown SOFC.